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Founded in 1864 by the late Dr. Henry Woodward, F.R.S.

Edited by

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and
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JANUARY—DECEMBER, 1937.

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THE
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VOLUME LXXIV.

No. I.—JANUARY, 1937.

ORIGINAL ARTICLES.

Arctic and Some Other Species of Streptelasma.

By Ian Cox, Sedgwick Museum, Cambridge.

(PLATES I and II.)

COLLECTIONS of fossils from the Lower Palaeozoic rocks of the Arctic usually contain species of *Streptelasma*. These, with other forms, have often been considered indicative of horizon. Now it is unfortunately true that none of the original descriptions or figures of species described from the Arctic, or of those relevant species long known in America, are adequate for strict identification. It is a matter for no surprise, therefore, that many false identifications have been made.

In order to overcome the difficulties that have arisen in this way, and to render the occurrences of *Streptelasma* of some use to Arctic stratigraphers, a redescription of certain species is attempted here. The most valuable guide to specific validity is internal structure (studied by means of thin sections); comparisons of external forms play a very subordinate part.

The species under consideration are :—

Streptelasma corniculum Hall, 1847, the genotype.

S. (?) *angulatum* (Billings), 1862, an unrecognizable species based on young individuals.

S. articum Wilson (*S.* ? *arcticum* Wilson 1931).

S. foerstei Troedsson 1928.

S. haysii (Meek) (*Zaphrentis haysii* Meek 1865).

S. poulseni sp. nov. (= *S. rusticum* (Bill.) of Troedsson 1928).

S. robustum Whiteaves 1897.

S. rusticum (Billings) (*Petraia rustica* Billings 1858).

S. trilobatum (Whiteaves) (*S. rusticum* var. *trilobatum* Whiteaves 1895; *S. latusculum* var. *trilobatum* Whiteaves of Lambe 1901).

Streptelasma sp. young (from Akpatok Island, N.W.T.).

? *Holophragma scheii* sp. nov. (= *S. corniculum* Hall, Holtedahl, 1913).

The synonymy lists given here are not necessarily complete. They only include those descriptions whose validity it has been possible to verify.

The work would have been impossible without the co-operation of certain curators who have been good enough either to lend or give me material from the collections in their charge. Most particularly I am happy to thank Dr. R. S. Bassler, of the U.S. National Museum, Miss Alice Wilson, of the Canadian Geological Survey, Dr. Christian Poulsen, of the Mineralogical Museum of the University of Copenhagen, and Dr. Trygve Strand, of the Paleontologisk Museum, Oslo.

The following abbreviations have been used: G.S.C., collection of the Canadian Geological Survey; M.M.K., Mineralogical Museum, Copenhagen; P.M.O., Paleontologisk Museum, Oslo; S.M., Sedgwick Museum, Cambridge; U.S.N.M., United States National Museum.

Genus STREPTELASMA Hall.

Smith's (1930, 311) interpretation of the genus is accepted here :—

Genoloctotype.—*S. corniculum* Hall, see C. F. Romer 1861, 19; and H. A. Nicholson and R. Etheridge, jun., 1879, 68.

Diagnosis.—Simple trochoid or conical Rugose corals, in which the more or less denticulate axial edges of the major septa twist to form a loosely built axial structure. In the neanic stages the septa are usually much dilated, and are laterally contiguous; but in the ephebic stages the dilatation is usually restricted to the peripheral border, where the short minor septa are laterally contiguous with the major and with them form a narrow stereozone. The irregular tabulae slope downwards and towards the periphery. Dissepiments are typically suppressed.[1]

Streptelasma corniculum Hall. Pl. I, Figs. 1–4.

Streptoplasma corniculum Hall, 1847, 69, pl. 25, figs. 1*a*–*d*.
Petraia ottawaensis Billings 1865, 429.
Streptelasma corniculum Nicholson 1875, 218–19 *partim*.
S. corniculum Winchell and Schuchert 1895, 90–1, pl. G, figs. 20 and 21 (excluding *S. crassa*, *S. multilamellosa*, and *S. parvula*).
S. corniculum Lambe 1901, 108, pl. vi, figs. 7–7*b*.
Not *S. corniculum* Edwards and Haime 1851, pl. 7, figs. 4–4*b*.
Not *S. corniculum* Holtedahl 1913, 9; 1917, 6.

Diagnosis.—Streptelasmas of moderately small size, curved trochoid; the septa are strongly dilated and laterally contiguous only in the very early stages. Stereozone narrow, usually about one-twenty-sixth the diameter; major septa at least twice as long as the width of the stereozone. Axial complex only moderately developed.

---

[1] The original wording has been slightly altered on Dr. Smith's own suggestion.

Horizon and Provenance.—*S. corniculum* is a Trenton species. The type localities are Trenton Falls, Middleville, Turin, Watertown in New York State.

Description.—The following remarks are based on specimens from Middleville, N.Y., and Ottawa and Cornwall, Ontario.

The corallum increases in diameter fairly constantly from the tip itself; its curvature decreases distally. The ornament consists of rugae and transverse striae. There are no interseptal ridges. The normal length of the corallum does not exceed 45 mm. and the corresponding diameter is about 27 mm. The calice has a maximum depth of about half the vertical height of the corallum; its floor is arched up axially, sometimes as much as 4 mm., above the periphery, but usually it is flatter than this.

Internally the species is characterized by the openness of the corallum. Even at the earliest stages the major septa, although strongly dilated, are only contiguous at the periphery and in the axial region. which is filled by the fusion of their ends.

In the ephebic stages the major septa are only very moderately dilated, sometimes they are wavy or slightly knotted. They tend to meet axially in pairs or groups but those septa that end free usually dilate and twist at the axial end. The cardinal septum is the strongest; the fossula is not very distinct. These are situated on the side of strongest curvature. The axial complex is relatively simple, being made up of a few slightly dilated septal ends, usually from the alar quarters.

The number of major septa in the ephebic region is about 45. Hall (1847, 69) gives 60, but this is probably accounted for by the smallness of his specimens and by his counting both orders of septa. Winchell and Schuchert (1895, 90) give a maximum of 60 major. I have never seen as many as this.

The tabulae are strongly up-arched, but usually approximately horizontal axially. In the specimens studied they vary in number from 8 to 13, complete and incomplete, in 10 mm. peripherally.

Remarks.—The species has a relatively constant external appearance. It is easily recognized in thin sections by its comparatively undilated septa, narrow stereozone, and simple axial complex.

Winchell and Schuchert (1895, 90–1), following Edwards and Haime (1851), Billings (1863), and Nicholson (1875), considered *S. crassa*, *S. multilamellosa*, and *S. parvula* Hall as synonyms of *S. corniculum*, " since so great a variation in the number of septa obtains." Over the limited number of specimens I have examined I have not observed a great variation in this respect. While it is possible that a study of a great number might show such a variation unaccompanied by variation in internal structure, no work has yet proved this to be the case. It is considered prudent therefore not to include these species in the present synonymy.

Lambe (1901, 108), who had compared the types, made it clear that *Petraia ottawaensis* Billings was conspecific with *S. corniculum*. *S. corniculum* as understood by Edwards and Haime (1851) is rejected, and that of Nicholson (1875) partly accepted in the present synonymy because Edwards and Haime interpreted and illustrated the species from specimens of *S. rusticum* (Bill.), although they refer to Hall and mention his localities. Nicholson also included *S. rusticum* with *S. corniculum*.

The specimens listed by Holtedahl (1913, 9; 1917, 6) from Ellesmereland as *S. corniculum* are not of this species. They are described on p. 15 as a new species of *Holophragma*.

Brown (1909, 56–8) has described the development of *S. corniculum*. He observes (p. 57) that " In no case do the septa meet and unite in the center to form a pseudo-columella. After they are fully developed they are apparently free at the center." This and his figures do not give a true impression of the internal structure, where an axial complex of not very advanced type does occur. This author (pp. 90, 95) considered that *S. rusticum*, a Richmond species, passed through the same development as *S. corniculum*, which is from the Trenton. After a study of many Ordovician species of this genus the present writer finds that he cannot agree that the relationship between these two forms is as close as Brown suggests (see his table, p. 95). Sardeson, in his proposal (1897) that many species of *Streptelasma*, as well as some Ordovician " *Zaphrentis* " should be regarded as conspecific, suggests the merging of species of *Streptelasma* which from a study of their internal structures can be shown to be distinct.

" *Streptelasma angulatum* (Billings)." Pl. I, Fig. 5.

Petraia angulata Billings 1862, 103, figs. 90 *a* and *b*; and 1866, 7.
Streptelasma angulatum Lambe 1901, 112.

Holotype.—G.S.C. 1984*a*. (The original of Billings's figure.)

Provenance.—Charleton Point and West End, Anticosti Island.

There are two syntypes of this " species ", of which the larger, the holotype, is more complete. It has a diameter of 15 mm. and a length of 14 mm. The tip is broken. The corallum is trochoid, probably with a very slight curve, which may have been greater at the tip. There is an acute angulation down the longest side. The ornament is rugose, with very fine striae. The calice is 6 mm. deep, flat axially, but depressed peripherally.

The septa are of two orders. There are about twenty major, which are dilated and laterally contiguous. They fill the axis. The minor septa are relatively long for such a size, being about one-eighth the diameter.

It is quite apparent that this is a young individual; a fact that Lambe (1901, 112) suggested from external examination. It is unrecognizable as a species. I have not been able to investigate Lambe's suggestion that it is a young angulated *S. selectum* Bill.

Streptelasma arcticum Wilson. Pl. I, Figs. 6–9.

Streptelasma ? arcticum Wilson 1931, 292–3, pl. ii, figs. 1–4 (but not specimen 6502, pl. ii, fig. 5).
Cf. *Streptelasma ? arcticum* Wilson, 1931, 293–4, pl. i, figs. 5, 6.
Not *Streptelasma rusticum* Troedsson 1928, which Wilson (1931) regarded as a synonym.

Holotype.—G.S.C. 6499. (Selected by Miss Wilson, 1931.)

Diagnosis.—*Streptelasmas* of moderately large size, trochoid, curving through 90 degrees. Septa not strongly dilated. The major septa are about one-third the diameter of the corallum in length. Stereozone distinct, usually about one-twelfth the diameter of the corallum. Axial structure complicated, of vermiform septal ends, arranged roughly about a dominant counter-cardinal plane. Tabulae closely placed in the ephebic stages. The calical floor bears a small boss.

Provenance.—The types were collected in 1925 from the drift of southern Baffinland. The holotype came from Koukjuak bay, on Lake Nettelling. Many specimens were collected by the writer from Akpatok Island, N.W.T. (Oxford Hudson Straits Expedition, 1931) from horizons that will probably prove to be equivalent to the Red River formation of Manitoba. (Foerste and Cox, 1936.)

Description.—The corallum widens fairly constantly, and the curvature, which at first is strong, decreases with age. The ornament is of strong, fairly coarse, and closely set rugae. A typical specimen has a length of 110 mm., with a diameter of 34 mm. The calice has a depth of about one-fifth the maximum length of the corallum; its floor rises fairly constantly to the central boss, which has parallel sides.

In youth the septa are strongly dilated, but usually are not contiguous for the middle third of their length. In the ephebic stages the major septa are moderately thin for the genus, taper axially, and mostly end free. Since their length is rarely more than one-third the diameter of the corallum a considerable area is left for the axial complex. The usual number of major septa in the adult region is about 60. The holotype, however, has 46 in a half-section, which would give 92. The cardinal septum is dominant and the fossula moderately distinct for the genus. The axial complex is distinctive. It consists of small vermiform pieces of septal end,[1] arranged roughly with respect to a dominant plane on the cardinal-counter diameter. The minor septa project a very short way beyond the stereozone and may abut on to the major septa.

The tabulae are very closely set in the adult; there are about 24 in 10 mm. Owing to the concentration of axial ends of septa on the counter-cardinal plane, the tabulae are frequently seen in longitudinal section to lie in a tectiform manner with respect to them; in such cases they never appear to be horizontal.

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[1] The references to " pieces " of septal end throughout this paper are to the appearance in transverse section. They are not, of course, separate from the septa, but are attached in a plane different from that of the sections in question. The septa in all these species are denticulate.

Remarks.—*S. arcticum* is easily recognized by its characteristic axial complex and the not infrequent tectiform appearance of the tabulae. Its external form is relatively constant, and is to be distinguished from unangulated *S. robustum* by its more slender appearance and stronger curvature. It is more rapidly expanding than *S. rusticum* and distinctly more curved. Its relatively greater size and coarser ornament distinguish it externally from *S. corniculum*, some of whose young stages resemble those of *S. arcticum* internally.

I had studied this species in detail before I was able to see Miss Wilson's types. But comparison of the Akpatok Island material with that from Baffinland shows them to be identical. The above description has been drawn chiefly from the former, because it is so much better preserved. The Baffinland holotype is fragmentary.

A study of internal structure shows definitely that the species is a *Streptelasma*, and that the horizontal elements are not dominant in the skeleton as Miss Wilson had suggested (1931, 293), for they become envolved where they encounter the major elements of the axial complex.

The specimen G.S.C. 6502, also figured by Miss Wilson (pl. ii, fig. 5) as *S. arcticum*, proves not to be conspecific with G.S.C. 6499, but resembles *S. foerstei* Troedsson more closely than any other species studied here.

Miss Wilson included *S. rusticum* Troedsson 1928 in her synonymy. A study of Troedsson's material, however, shows that it should be regarded as a new species (see p. 10).

Whiteaves, who identified the few fossils collected by Bell (1897, 79, 82–3) from Akpatok Island, lists (1899, 433–4) *S. robustum*. Since there is only one specimen of this in the collection made by the present writer in 1931, while *S. arcticum* is, without doubt, the most common fossil on the island, it is very possible that Whiteaves regarded specimens of *S. arcticum* as *S. robustum*; especially as he writes that the latter is very common there. Unfortunately Bell's collection is lost, so there is no opportunity of verifying this.

Streptelasma foerstei Troedsson. Pl. I, Figs. 10–16.

Streptelasma foerstei Troedsson 1928, 109, pl. 25, figs. 1, 3; pl. 26, fig. 5.

S. robustum Troedsson 1928, 108, pl. 24, figs. 1, 2, 4, 6, 7, 8; pl. 25, fig. 2.

S. robustum var. *amplum* Troedsson 1928, 108, pl. 26, figs. 1–4.

Holotype.—M.M.K. 116 (Jubilaeumsekspeditionen Nord om Grønland) (by author's designation).

Diagnosis.—*Streptelasmas* often of very considerable size, with a curved triangulate [1] corallum. Degree of thickening of internal elements very variable. Axial complex somewhat variable, but usually well developed from the anastomozing ends of septa from the alar quarters.

Provenance.—The types were collected from the Cape Calhoun formation of North-West Greenland. At the moment this is regarded as being of Richmond age. (Koch 1929, 30, 37.)

Description.—The largest specimen examined had a maximum diameter of about 40 mm. The ornamentation is of fairly coarse and somewhat irregular rugae. In young stages the internal structure appears to vary with external form, in that compressed forms show dilated septa completely filling the lumen, while those that are more expanded have strongly dilated septa which taper axially so that they are not laterally contiguous for the greater part of their length. In the ephebic stages the major septa are hardly dilated and taper axially; the stereozone is narrow, and the axial complex is formed of pieces, rather than lengths, of septal end.[2] But the neanic stages seem to occupy by far the greater part of the length of the corallum in most of the specimens. Here the septa are strongly dilated and may even completely fill the lumen; when they do not the stereozone is wide. In this region, too, the axial complex is not broken up, and it consists of the more or less thickened ends of septa, usually from the alar quarters. The maximum number of major septa observed in ephebic stages was 92, but more usually the number is 70–80.

The calice has a depth of about three-fifths the height of the corallum, and its floor domes up to about 5 mm. above the level at the periphery. The tabulae arch upwards, but are most steeply inclined peripherally; apparently they are never really horizontal axially. At the distal end of a large corallum there are usually about 10 in 10 mm.

Remarks.—*S. foerstei* is easily recognized by its strikingly triangulate form and characteristic internal structure; by its septa being numerous, its minor septa very short, and its stereozone usually pronounced; also by the tendency in neanic stages for the infilling of interseptal loculi.

Troedsson (1928, 109) described this species from its external form alone, and distinguished it from *S. robustum* Whiteaves, as he understood that species, by its "strong trilobation". After examining nearly all the material of *S. foerstei* and *S. robustum* Troedsson, the present writer has found it impossible to differentiate it into two groups. It is true that most of the specimens labelled

---

[1] The term *triangulate* is introduced to cover that form of corallum in which three longitudinal angulations are sufficiently strong to give the corallum a triangular, subtriangular, or roughly angular pear-shaped transverse section. Hitherto some authors have employed the term *trilobate* to describe this shape, but the word is obviously misused in this sense.

[2] See footnote on p. 5.

S. foerstei are more triangulate than those called *S. robustum* by Troedsson (these are also "trilobate"), but a study of internal structure supports the view that this is only due to individual variation. It must be remembered that individual variation within this species is considerable. Troedsson's reference of part of this material to *S. robustum* is unsupported by a study of internal structure, which shows Whiteaves' species to have fewer and much more dilated septa, a simpler axial complex, narrower stereozone, and more remote tabulae. *S. robustum* of Troedsson, therefore, becomes a synonym of *S. foerstei* Troedsson.

Thin sections of a specimen of *S. robustum* var. *amplum* Troedsson, which apparently was distinguished by its shape, show that it also belongs to *S. foerstei* Troedsson. (See Pl. I, fig. 15)

It is pointed out on p. 14 that *S. trilobatum* (Whiteaves) possibly represents the young of this species. It would be interesting to compare the types of Miss Wilson's (1931, 11, 12) *S. prolongatum* with those of *S. foerstei*, some of which they seem to resemble closely. *S. prolongatum* is found in the Richmond of the Beverfoot Range, B.C.

Streptelasma haysii (Meek). Pl. II, figs 4*a–b*.

Zaphrentis haysii Meek 1865, 32.
Streptelasma haysii (Meek) Kirk 1925, 446.
S. haysii (Meek) Ladd 1928, pl. iv, figs. 3–5 only.

Holotype.—U.S.N.M. 2563 (see Ladd 1928, pl. iv, figs. 3–5).

Provenance.—The types of *S. haysii* came from Cape Frazier, Ellesmereland. Kirk (1925, 446) has studied the associated fauna and compares it with the pre-Fernvale Richmond fauna of the lower part of the Bighorn dolomite of Wyoming, but remarks on its similarity with the typical Richmond fauna.

Description.—The holotype is the only specimen which approaches completeness. Its proximal end is missing. Ladd has figured three external views of it. The corallum is apparently curved triangulate, with an apical angle of about 40 degrees (as far as can be judged). It is rolled but shows traces of rugae. In the calical view over ninety septa of both orders can be seen; but Meek wrote "principal radial septa about sixty, rather stout and rigid, as seen around the margin of the calice . . . alternating with these there is a shorter and weaker secondary series."

The writer has been able to study one of Meek's metatypes. It bears the same catalogue number as the holotype. It is broken and shows only part of the ephebic region of the corallum. Rolling obscures the exterior. The maximum diameter is 32 mm. The calical floor is raised centrally by about 2·5 mm. The major septa are moderately thin for the genus, although thickened peripherally; they taper axially, but usually end with a slight dilatation. There is the usual tendency for the axial ends of the septa to join with their neighbours, sometimes accompanied with twisting. The cardinal fossula is wide and situated on the *concave* side. The cardinal septum is even less conspicuous than is the rule in this genus. The axial complex is composed of fairly long and not very thickened anastomozing septal ends, with a few isolated pieces. These result in a fairly extensive but loose structure. The minor septa are very short and fine. The stereozone is about 1 mm. wide. At a maximum diameter of 19 mm. there are 47 major septa. The tabulae arch upwards peripherally, and there are 6 in 10 mm.

The noticeable features of this specimen are the relative thinness and separation of the septa, the long anastomozing elements of the axial complex, and the situation of the fossula on the shortest side.

The section figured gives an erroneous impression of the normal shape in transverse section. (Pl. II, fig. 4*b*.)

Remarks.—Kirk (1925, 446) examined Meek's type and made observations on its external form. Ladd (1928, pl. iv, figs. 1, 2) has figured a specimen from the Maquoketa of Iowa (State Univ. of Iowa, No. 2–050), which he identifies with this species, but he has not yet examined the internal structure. The present writer has been unable yet to obtain sections of this specimen, and, while recognizing the similarity between its external appearance and that of Meek's rolled type, prefers on this account not to include it in the present synonymy.

Streptelasma poulseni sp. nov. Pl. II, figs. 8*a–c*, 9*a–b*.

Streptelasma rusticum (Billings) Troedsson 1928, pl. 24, figs. 3, 5, pl. 25, fig. 4.

Holotype.—M.M.K. 182 (Jubilaeumsekspeditionen Nord om Grønland).

Diagnosis.—*Streptelasmas* of usually moderate size, though sometimes fairly large, curved, trochoid. Septa only moderately dilated; minor septa short and project very little from the stereozone, which is narrow. Axial complex simple, formed by the amalgamation of the ends of few septa. Tabulae relatively remote and only very gently inclined.

Provenance.—The types of *S. poulseni* were collected from the Cape Calhoun formation, North-West Greenland, which at the moment is regarded as being of Richmond age. (Koch 1929, 30, 37.)

Description.—The corallum of this species, which is rather slender trochoid, curves through about 90 degrees. The largest specimen measured had a maximum length of 70 mm. and a corresponding diameter of 27 mm. All the material is rolled, but there is evidence of rugae, which were neither coarse nor very regular.

In the young the septa, although much dilated, are not quite laterally contiguous. The cardinal septum dominates the lumen.

In the ephebic region up to 53 major septa have been observed. These are only very moderately dilated. As a rule their axial ends meet to give a few bundles, while a few, usually from the alar quarters, continue into the axial region and produce a simple complex. The minor septa are short and thin, rarely projecting much from the stereozone, which is 1–2 mm. wide. The calice has a very gently arched to almost flat floor. The tabulae are very simple in appearance, usually complete and only gently inclined. There are about 7 in 10 mm.

Remarks.—Troedsson, who first examined Koch's material (here described), has identified the specimens as *S. rusticum* (Bill.), although his remarks (1928, 107) seem to imply that he had in mind *S. robustum* Whiteaves and not *S. rusticum*. He states they are "large and robust", the words used by Whiteaves 1886, 57, in his first recognition of *S. robustum* as "*Streptelasma corniculum* ? Hall. Large and robust variety". Also the typical localities Troedsson quotes (presumably from Bassler, 1915) are those of *S. robustum*, not *S. rusticum*. Similarly his remarks on *S. robustum* (108) seem to apply to *S. rusticum* (Bill.), not *S. rusticum* (Bill.) Troedsson, for he says: "This is abundantly represented in all divisions of the Richmond in the United States."

The internal structure of *S. poulseni* has more in common with that of *S. rusticum* than with any other species described here. It differs in the narrower stereozone and the shortness of its minor septa in typical individuals, and in the thinner septa, which are hardly dilated at all. The tabulae, too, are more remote. Its axial complex is of the same type, but in the younger stages does not appear as if it were broken up into isolated elements, and it is much less dilated.

The species is given the name of Dr. Christian Poulsen, Curator of the Mineralogical Museum, Copenhagen.

Streptelasma robustum Whiteaves. Pl. II, figs. 1–3.

Streptelasma robustum Whiteaves 1897, 153–4, pl. xviii, figs. 1, 1*a*.
S. robustum Lambe 1901, 109–110, but not pl. vii, fig. 1.
Not *S. robustum* Troedsson 1928, 108, pl. 24, figs. 1, 2, 4, 6–8; pl. 25, fig. 2.

Types.—The types are lost.

Diagnosis.—*Streptelasmas* of large robust curved trochoid form. Septa very dilated; axial complex of few dilated anastomozing septal ends.

Provenance.—The types of *S. robustum* came from the Red River limestone at Fort Garry, Manitoba. The species occurs also on Akpatok Island, N.W.T., and was found by the present writer while on the Oxford Hudson Straits Expedition, 1931, in strata that will probably prove to be equivalent to part of the Red River formation (Foerste and Cox 1936).

Description.—The species is gross in appearance and usually fairly strongly curved. The ornament takes the form of rugae and striae. Although some specimens are nearly circular in section, others may be somewhat angulate longitudinally both on the convex side and on those at 90 degrees to it. The cardinal fossula corresponds in position to the first of these sides. The maximum length may be as much as 180 mm. with a diameter of 57 mm. The calice is relatively shallow.

In the early stages the septa are very strongly dilated, but usually are not quite laterally contiguous except peripherally. The stereozone is about one-fourteenth the diameter of the corallum. The majority of the major septa extend for about one-third the diameter; their ends usually join up with each other. The axial region is occupied by the much thickened ends of a few septa; these anastomose and join up with their opposites. Thus the elements of the axial complex are few, but very strong. The cardinal septum and fossula are only moderately seen. The minor septa project a very little from the stereozone. The tabulae are fairly strongly developed; they arch upward from the periphery but are almost horizontal axially. They are mostly complete, and about 8 lie in a length of 10 mm.

Remarks.—The specimens collected from Akpatok Island correspond very closely with those types I have examined. The material described by Troedsson (1928, 108, pl. 24, figs. 1, 2, 4, 6–8; pl. 25, fig. 2) as *S. robustum* is conspecific with that author's *S. foerstei*, and has already been considered.

The correspondence between the Akpatok specimens and the types from Manitoba is very close, and it may be significant that an example from Baffinland, not far removed from the former locality, is rather different. This specimen was collected by Soper from the drift of Snowgoose Bay, L. Nettelling, Baffinland. It was superficially described by Miss Wilson (1931, 294, pl. i, fig. 7) as *Streptelasma* cf. *robustum* Whiteaves. It is water-worn. The maximum length is about 150 mm. and the diameter 60 mm. The corallum is strongly curved, apically trochoid, and distally ceratoid. The septa are of two orders, and there are as many as 97 major septa. The specimen is certainly of *S. robustum* type, but most of the elements in the adult regions are much less thickened than in typical examples. This is particularly the case in the axial complex, in which there are many more "detached septal ends", which anastomose and join up with those of the opposite septa in the usual way, but are unthickened.

Streptelasma rusticum (Billings). Pl. II, figs. 11, 12*a*–*c*, 13*a*–*d*.

Petraia rustica Billings 1858.
P. canadensis Billings 1863.
Zaphrentis canadensis Billings 1865.
Streptelasma corniculum Edwards and Haime 1851, pl. 7, figs. 4–4*b* *partim.*
S. corniculum Nicholson 1875, 218–19 *partim.*

S. rusticum (Bill.) Winchell and Schuchert 1895, 93.
S. rusticum (Bill.) Lambe 1901, 111.
S. dispandum Foerste 1909, 307 ; 1924, 66.
S. rusticum (Bill.) Bassler 1815.
S. rusticum (Bill.) Foerste 1924.
Not *S. rusticum* (Bill.) Troedsson 1928, or Koch 1929.

Holotype.—The author's types are lost.[1]

Diagnosis.—*Streptelasmas* of moderate to large size, with more or less inflated ceratoid to trochoid coralla ; straight for the greater part, but more or less curved proximally. Major septa rather strongly dilated. Axial complex of swollen elements which in transverse section appear to be isolated. Stereozone relatively wide, usually about one-eighth the diameter. Minor septa completely embedded in, or projecting very little from, the stereozone.

Provenance.—*S. rusticum* is a Richmond species. The type locality is Snake Island, Lake St. John, Quebec. The types of *Z. canadensis* came from Drummond Island, Lake Huron, and specimens have also been collected from Cape Smyth, Lake Huron. Lambe (1901, 111) says he compared the latter with the types.

Description.—This species reaches a considerable size. There is a specimen in the Sedgwick Museum (Lyell Collection) over 90 mm. long and with a diameter of 35 mm., but the majority of specimens I have examined are of more moderate size, averaging about 50 mm. in length. There seems to be a fairly considerable variation also in the apical angle, especially in the smaller specimens, some of which are definitely trochoid. But this is probably more apparent than actual, being due to the early removal (by rolling) of the extreme proximal end, which is relatively more slender than the adult part. The degree of curvature is variable, but always decreases distally, the major portion of the corallum usually being straight. The external ornament consists of rugae alone ; there is no longitudinal ornament in fresh material.

Not unusually the corallum has a slightly greater diameter in the plane of bilateral symmetry than in that at right angles to it.

The internal structure of *S. rusticum* seems to vary somewhat over the specimens examined. The calice has a depth of about two-fifths the length of the corallum in the moderately sized examples ; its floor is somewhat irregular and slightly arched axially. In the young stages the septa are very strongly dilated and completely fill the lumen. Here the cardinal septum is the most prominent and dilates axially. The axial complex proper is not formed early, and its place is taken in youth by the dilated ends of a few septa, on to which the others abut. Much dilated pieces of septal end usually form the axial complex, and these may appear isolated or anastomozing in transverse sections. The latter is the rule in the larger specimens, which usually have less dilated septa. The maximum number of major septa observed was 62. The cardinal fossula is, perhaps, more distinct than in most of the other species considered here. The secondary septa are usually completely embedded in the stereozone, but they may project a little from it. The stereozone is typically pronounced, being often more than one-eighth the diameter. The tabulae are relatively remote, and tend to be nearly horizontal axially.

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[1] Personal communication from Mr. E. M. Kindle.

The variations in the specimens examined are chiefly in the width of the stereozone and the number of elements in the axial complex. The latter seems to increase with age in the individual and is accompanied by a general decrease in inflation of the individual elements and the achievement of a more orderly arrangement in the whole structure.

Remarks.—*S. rusticum* is distinguished in thin sections by its relatively thick septa, fairly wide stereozone enveloping the minor septa, and characteristic axial structure. Externally the straightness of the greater part of the corallum gives a good indication of the species.

S. dispandum Foerste is included in the synonymy after examination of a specimen from the U.S. National Museum. Foerste (1909, 307; 1924, 66) distinguished this species by the more rapid expansion of the corallum, especially in the young; but a study of internal structure shows no specific difference from *S. rusticum.*

Lambe (1901, 111) compared the types of *P. rustica* and *Z. canadensis* and found them to be conspecific. He also points out how Billings's (1862) figures of the latter are misleading in that they show differences from *P. rustica* which cannot be seen in the original material. Lambe, as well as Winchell and Schuchert (1895, 93), regards Edwards and Haime's figures of *S. corniculum* (1851, pl. 7, figs. 4–4*b*) as being of *S. rusticum,* since they have the typical shape of this species and lack the shorter and much more curved form of the former. There seems no reason to doubt that Lambe's view is correct. It is also highly probable, from the measurements he gives, that Nicholson (1875, 218–19) was including specimens of *S. rusticum* in his description of *S. corniculum.*

Troedsson's "*S. rusticum*" (1928, 107, pl. 24, figs. 3, 5, 9, and pl. 25, fig. 4) from North-West Greenland, have been shown above to be a new species—*S. poulseni.*

Streptelasma trilobatum (Whiteaves). Pl. II, figs. 5*a–c*.

Streptelasma rusticum var. *trilobatum* Whiteaves 1895, 113.
S. latusculum var. *trilobatum* Lambe 1901, 115.

Types.—The author's types are lost.

Provenance.—Stony Mountain Formation, Manitoba.

I have examined two specimens of this species from Stony Mountain, in the collection of the Geological Survey of Canada, and am inclined to the view that they are young forms. The corallum is trochoid and slightly curved, triangulate with angulations obtusely rounded, and that of the longest side dominant. Between the angulations the surface is markedly concave. The maximum length observed was 34 mm. with a diameter of 25·5 × 24·5 mm.

In the most distal part of the corallum the septa are of two orders, with 47 major. They are inflated and taper axially, being laterally contiguous for the greater part of their length. The cardinal septum is the most swollen and corresponds in position to the angulation of the longest side. The minor septa are short, but, the specimens being rolled, their true length cannot be measured. The axis is filled with the swollen ends of septa. The calice is shallow.

Lambe (1901, 115) regarded *S. trilobatum* as a variety of *S. latusculum* Billings (pl.iii, fig. 10), but my comparison of the internal structures of the two does not support this view. I have examined a number of specimens of *S. latusculum* and find that the septa are much less numerous and less swollen then in *S. trilobatum*, and are arranged almost radially. It has also a distinct, but narrow, stereozone and an open axial complex of few elements. I do not therefore consider that *S. trilobatum* is a variety of Billings's species, and prefer for the time being at any rate to call it *Streptelasma trilobatum.*

It is possible, however, that *S. trilobatum* may represent the young of *S. foerstei* Troedsson. If this proves to be the case, then *S. foerstei* will become a synonym of *S. trilobatum*. But since I have not been able to examine more than two specimens of the latter, I can do no more than suggest the possibility, and say that sections of it are indistinguishable from those of some young *S. foerstei*, except that their minor septa are probably shorter—which might be an individual character. In exterior view the angulations are more rounded and the surface between them more excavate in *S. trilobatum* than in young *S. foerstei.*

? *Streptelasma* sp. Pl. II, figs. 6, 7.

A few very small trochoid forms were collected from Akpatok Island at an elevation of about 450 feet, in a probably infra-Richmond assemblage. On account of the paucity of the material and the strong probability that they are young individuals no trivial name is given.

The coralla are gently curved and show a maximum length of 13 mm., a diameter of 10 mm., and an apical angle of about 40 degrees. The exterior is ornamented with very fine striae and very fine interseptal ridges, fine striae and subdued rugae. The calice occupies about half the height of the corallum, and has a flat floor, except at the periphery, where it slopes abruptly downwards. The remote tabulae reflect this arrangement. In the distal part of the coral there are 30 major septa, which are dilated and usually reach the axis, in which region the ends become contiguous. The stereozone is about one-ninth the diameter, and from this the minor septa project a little. There is no true axial complex, although the ends of the septa reach and occupy much of this region. This strongly recalls the situation in young stages of certain other species of this genus; but usually in these the corallum has reached a fair size before it is seen, the septa at such very small diameters almost completely filling the lumen.

These specimens come closest, perhaps, to Miss Wilson's (1926, 11) *S. fragile*, but the description of the internal structure of this being incomplete it is not possible to compare the most diagnostic features. *S. fragile* expands much less rapidly and has fewer septa.

Externally these Akpatok specimens are not unlike *S.* (*Paleophyllum*) *divaricans* Nich., but they differ in being solitary and in internal structure. Their septa are more dilated and the cardinal septum is more distinct, also the tabulae are much more remote. Incidentally it is possible that the corallites in *P. divaricans* are not as closely associated as hitherto thought. From the few specimens I have sectioned it seems that they are growing in close association rather than one from out of the other. However much more material would have to be examined before such an observation could be made positive.

Genus HOLOPHRAGMA Lindström.

Holophragma Lindström 1896, 35.

Genotype (by monotypy).—*Hallia calceoloides* Lindström 1866, 289, pl. xxxi, figs. 9–11. Salopian, Gotland.

Diagnosis.—Subcalceoloid rugose corals typically small and slender with typically a very oblique calice; with septa which are laterally contiguous for the greater part of their length and a counter septum [1] longer and stouter than the rest. The cardinal fossula is situated on the convex side of the corallum and is occupied by a very short cardinal septum.

? *Holophragma scheii* sp. nov. Pl. II, figs. 14–16.

Streptelasma corniculum Holtedahl 1913, 9; 1917, 6.

Syntypes.—P.M.O. A 10585–8.

Diagnosis.—Corallum small, subcalceoloid. Septa very thickened; when they are not contiguous for all their length there is a distinct and relatively very wide stereozone. Typically with a large dense axial fusion of thickened septal elements, confluent with the septa of the counter quarter and continued up into the calyx as a rod. Cardinal fossula distinct and situated on the shorter side of the corallum. Cardinal septum very short.

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[1] The position of the counter septum is often indicated on the exterior of the flattened side of the coral by a strong ridge, which is actually formed by two strong intersceptal ridges separated only by a faint central groove.

Provenance.—The types of this species were collected by Per Schei in 1899 from Strandpilaren, Norman Lockyer Island, Princess Marie Bay, Ellesmereland. Holtedahl (1913, 9; 1917, 6) listed them as *S. corniculum*, and this identification corresponded with his view that the associated fauna was Trenton. I have discussed the age of this fauna elsewhere with respect to the specimen of "*Calapoecia canadensis*", which occurs in it; this is the more advanced form *C. canadensis* var. *anticostiensis* Bill. (Cox, 1936). It does not seem unlikely that this Ellesmereland fauna is really of post-Trenton age.

Description.—Among the syntypes the only corallum approaching completeness (A 10586) is subcalceoloid, but from a study of all the material it appears that the flattened side becomes more rounded distally. The external ornamentation is of both longitudinal and transverse striae, the latter sometimes assuming the proportion of faint rugae. The maximum median length observed was 19 mm. and the diameter the same. The apical angle is about 50 degrees. The calice is 9 mm. in depth and has a flat floor, through the centre of which the axial structure continues up as a solid tapering rod.

Internally the species is characterized by a remarkable thickening of the septal elements, which usually takes the form of a very wide and dense stereozone and a solid subcylindrical axial structure in the ephebic parts of the corallum. The latter is formed by the ends of only a few septa from the counter quarter, and is otherwise free. As a rule the septa are in lateral contact everywhere except in the middle third (or less) of their length. But sometimes the elements are so thickened that the lumen is practically solid. The septa appear to be of two orders, but the state of preservation makes it impossible to be certain on this point. The cardinal fossula is situated on the shorter (i.e. curved) side, and is usually wide. The cardinal septum is short and retreats from the axis in ephebic stages.

Remarks.—This species is assigned tentatively to the genus *Holophragma*. Specimens of *H. calceoloides* Linds, the only species of the genus described hitherto, have been compared with Schei's specimens and correspondence in the following points was noticed: Both are roughly calceoloid and become more cylindrical distally; in each case the cardinal fossula is situated on the curved (or, in longitudinal section, shorter) side, and the cardinal septum is short; the septal elements are very thickened, especially axially about the ends of the septa of the counter quarter. But, on the other hand, the species differ in shape, *H. calceoloides* being a very small and rather slender form, with an oblique calical rim, while ? *H. scheii* is wider and has a less oblique calice. In the genotype there is, in the calice, no spine-like continuation of the axial structure, formed by the coalescence of the swollen ends of the counter septum and its immediate neighbours, as seen in *H. scheii*, but the counter septum lies above the level of the others and is swollen axially. The septa of ? *H. scheii* are not contiguous to the same degree as those of the genotype.

? *H. scheii* may or may not be intimately related to the Salopian *H. calceoloides*. It is very possible that it is a member of the earlier *Streptelasmidae* which has followed the same trend of development as *Holophragma calceoloides*. Indeed the form of the axial complex in all but the ephebic stages of *H. scheii* recalls that seen in a few young specimens of *Streptelasma*, where there is (apparently individually developed) thickening about the ends of the septa. The position of the cardinal fossula and the solid nature of the axis in the ephebic regions are the principal differences from *Streptelasma*.

The species has been given the name of its collector, Per Schei.

A single fragmentary specimen from Akpatok Island (from an elevation of 270 feet) may belong to this species, or one allied to it. It shows a maximum diameter of 21 mm. It does not correspond exactly with the types, for it has a circular section and looks at first sight like a *Streptelasma*. But internally it shows a solid axial structure attached to the septa of the counter side and a short cardinal septum. The axial structure continues up into the calice as a solid blunt boss. A similar appearance was observed in one specimen of undoubted *H. scheii*, but usually in this species it is seen as a spine in the calice.

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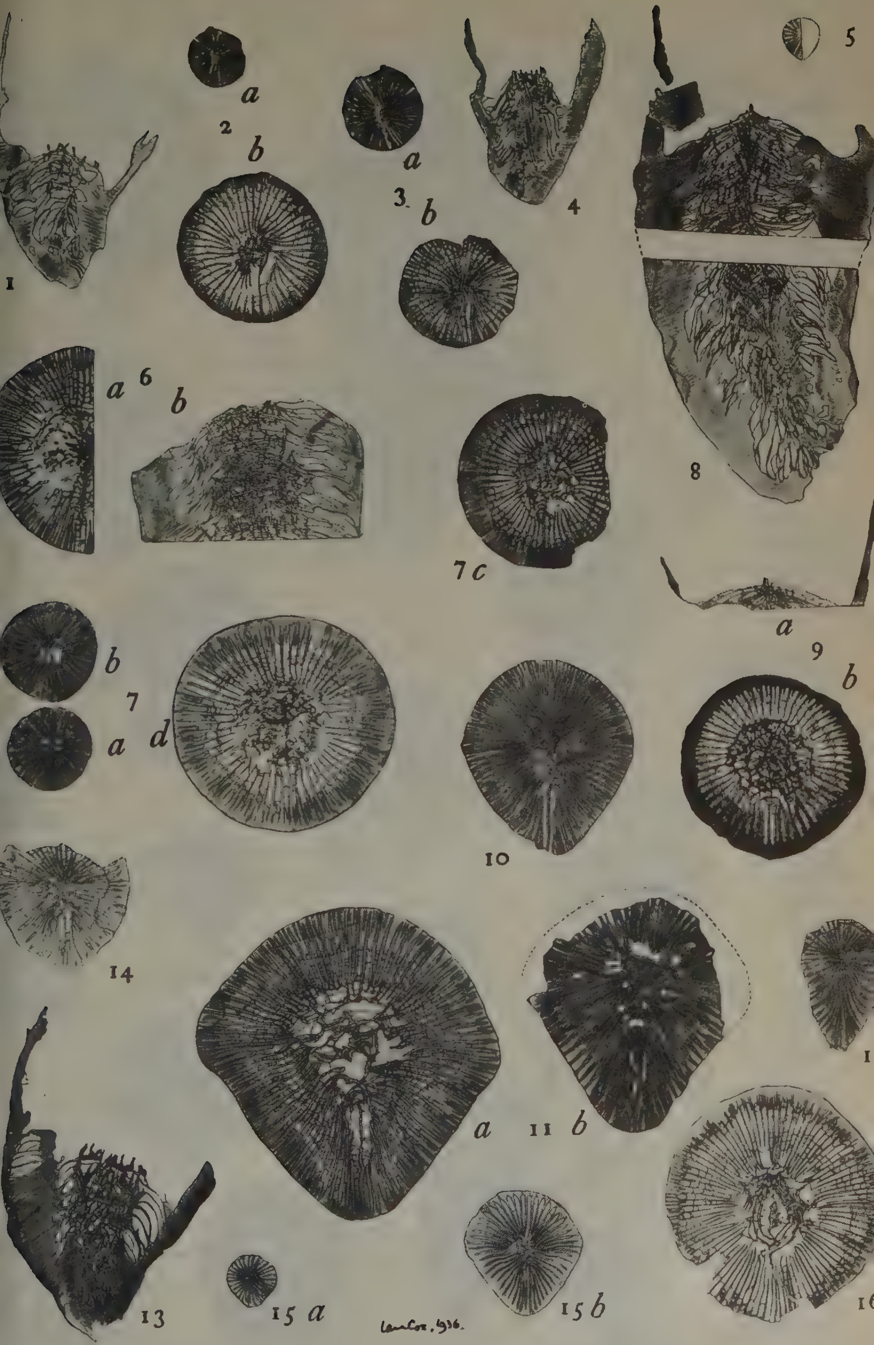
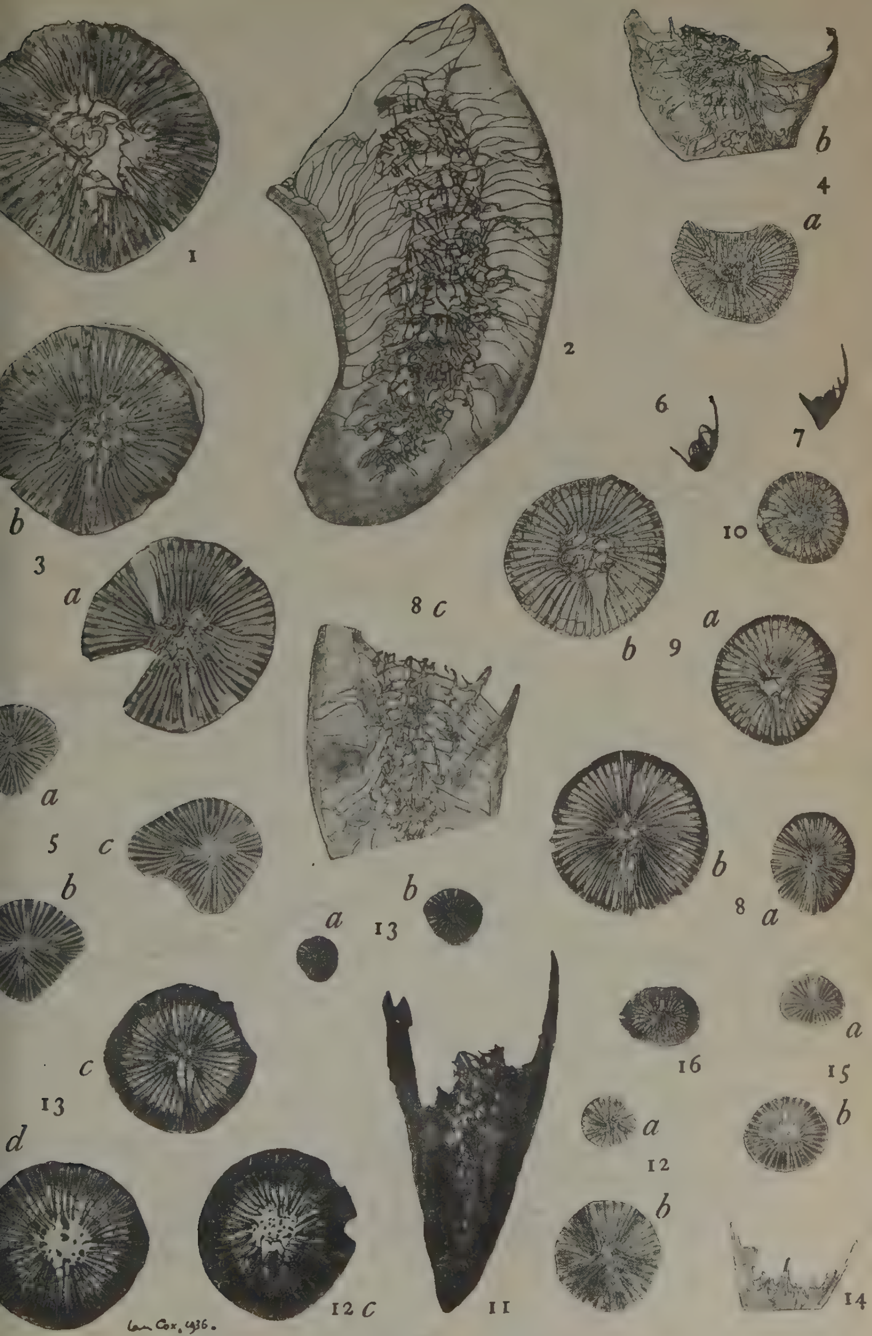


ARCTIC AND OTHER SPECIES OF STREPTELASMA.

[To face p. 18



ARCTIC AND OTHER SPECIES OF STREPTELASMA.

DESCRIPTION OF PLATES I AND II.

(All figures are natural size and were drawn with the aid of a *camera lucida.*)

PLATE I.

Streptelasma corniculum Hall, *S. articum* Wilson, and *S. foerstei* Troedsson.

FIG. 1.—*S. corniculum* Hall, from the Trenton limestone, Middleville, N.Y., U.S.N.M. 322 D.

FIG. 2.—*S. corniculum* Hall, from Cornwall, Ontario. S.M. A 7861.

FIG. 3.—*S. corniculum* Hall, from Cornwall, Ontario. S.M. A 7860.

FIG. 4.—*S. corniculum* Hall, from Ottawa, Ontario. S.M. A 7859.

FIG. 5.—" *S. angulatum* Billings." Section of the holotype, showing that it is a young individual. G.S.C. 1984*a*.

FIG. 6.—*S. arcticum* Wilson. Sections of the holotype from the drift of Koukjuak Bay, Baffinland. G.S.C. 6499.

FIG. 7.—*S. arcticum* Wilson, from Akpatok Island, N.W.T. S.M. A 7868.

FIG. 8.—*S. arcticum* Wilson, from Akpatok Island, N.W.T. S.M. A 7867.

FIG. 9.—*S. arcticum* Wilson, two sections from the same specimen. Akpatok Island, N.W.T. S.M. A 7866.

FIG. 10.—*S. foerstei* Troedsson, from the Cape Calhoun Formation, Cape Calhoun, N.W. Greenland. M.M.K. 160.

FIG. 11.—*S. foerstei* Troedsson, from Cape Calhoun. M.M.K. 167.

FIG. 12.—*S. foerstei* Troedsson, young, from Cape Calhoun. M.M.K. 175.

FIG. 13.—*S. foerstei* Troedsson, young, from Cape Calhoun. M.M.K. 169.

FIG. 14.—*S. foerstei* Troedsson, young, from Cape Calhoun. M.M.K. 192.

FIG. 15.—*S. foerstei* Troedsson, young individual from Bessels Fjord, N.W. Greenland. Metatype of *S. robustum* var. *amplum* Troedsson. M.M.K. 711.

FIG. 16.—*S. foerstei* Troedsson, showing the circular shape to which the triangulate may pass distally. M.M.K. 189.

PLATE II.

Streptelasma haysii (Meek), *S. latusculum* (Bill.), *S. poulseni* sp. nov., *S. trilobatum* (Whiteaves), *S. rusticum* (Bill.), *S. robustum* Whiteaves, *Streptelasma* sp. and ? *Holophragma scheii* sp. nov.

FIG. 1.—*S. robustum* Whiteaves, topotype from Lower Fort Garry, Man. Collected by T. C. Weston in 1884. G.S.C. 6880*a* and S.M. A 7863.

FIG. 2.—*S. robustum* Whiteaves, from Graston Quarry, Tyndall, Man. G.S.C. 6880 and S.M. A 7864.

FIG. 3.—*S. robustum* Whiteaves, from Akpatok Island, N.W.T. S.M. A 7865.

FIG. 4.—*S. haysii* (Meek), one of Meek's metatypes. U.S.N.M. 25683.

FIG. 5.—*S. trilobatum* (Whiteaves), from Stony Mountain, Man. G.S.C.

FIGS. 6 and 7.—*Streptelasma* sp., from Akpatok Island, N.W.T. S.M.

FIG. 8.—*S. poulseni* sp. nov., sections of the holotype, from the Cape Calhoun Formation, N.W. Greenland. M.M.K. 182.

FIG. 9.—*S. poulseni* sp. nov., from Cape Calhoun. M.M.K.

FIG. 10.—*S. latusculum* (Bill.), from the Jumpers River, Anticosti Island (collected in 1856). G.S.C.

FIG. 11.—*S. rusticum* (Bill.), small specimen from Manitouaning, Manitoulin Island, L. Huron. G.S.C. 8530*b*.

FIG. 12.—*S. rusticum* (Bill.), small specimens from the same locality. G.S.C. 8530*c*.

FIG. 13.—*S. rusticum* (Bill.), small specimen from the "Cincinnati Group", Waynesville, Ohio. S.M. A 3424.

FIG. 14.—? *Holophragma scheii* sp. nov., syntype from Strandpilaren, Norman Lockyer Island, Ellesmereland. P.M.O. A 10586.

FIG. 15.—? *H. scheii* sp. nov. syntype from Strandpilaren, Norman Lockyer Island, Ellesmereland. P.M.O. A 10587.

FIG. 16.—? *H. scheii* sp. nov., syntype from Strandpilaren, Norman Lockyer Island, Ellesmereland. P.M.O. A 10585.

Further Observations on the Ballantrae Igneous Complex, South Ayrshire.

By D. Balsillie, Royal Scottish Museum.

I. Metamorphosed Dolerites and Gabbros.

IN the southern belt of the Ballantrae serpentine, stretching south-west from Millenderdale, there occur many exposures of altered and more or less recrystallized dolerite and gabbro. Some of these rocks have afforded considerable difficulty to previous observers and they have been variously interpreted. Thus Dr. G. W. Tyrrell, in an interesting paper published twenty-five years ago (*Trans. Geol. Soc. Glas.*, xiii, 283), regarded some of the rocks on Littleton Hill as " relics of an older mass of dolerite or gabbro " that had " become enveloped by the later serpentine ". But this expression of opinion does not appear to have been founded upon conviction, since quite recently Tyrrell states (*Proc. Geol. Assoc.*, xliv, 59) " contact metamorphism presumably by the enveloping serpentine seems to have been developed in rocks on Littleton Hill which may originally have been spilites and diabase porphyrites ". At the time of writing a previous paper (Geol. Mag., LXIX, 1932, 107) I had already inferred that the metamorphic rocks seen on Littleton Hill must have been derived from dolerites and gabbros, but the nature of their association with the serpentine was then merely a matter of surmise. In continuing field work in the province, therefore, I kept in mind the requirement to determine, if possible, the true geological relationships of these rocks, and to that end I have re-investigated carefully the whole southern outcrop of the serpentine and its accompanying metamorphic masses. A short account of the results of the field and laboratory work is given below. Firstly, however, I take leave to acknowledge the very helpful character of Mr. A. G. Macgregor's researches on felspar clouding, " a characteristic effect that is often produced in the fresh plagioclase felspars of igneous rocks by thermal metamorphism " (see *Min. Mag.*, xxii, 524). Application of Mr. Macgregor's principle in the Lizard district of Cornwall permits the interesting and important observation that a dolerite black dyke with chilled edges may exhibit distinct evidence of contact alteration, no traces of which are to be detected in the contiguous serpentine. From this, perhaps, we should infer the immunity of olivine to thermal change and a relatively late date for the process of serpentinization.

For the purpose of indicating concisely the character of the metamorphic rocks referred to in the following notes I divide the province in which they occur—the southern belt of serpentine, stretching from Duhorn Shore to Millenderdale—into two parts. The first area takes in the country lying to the east of the Garnaburn–Lendalfoot road, and the second includes the remaining part of the moor, extending from the same boundary to the sea.

Among the altered dolerites and gabbros east of the Garnaburn road we find even-grained 0·25–0·5 mm. granulites, consisting of soda-lime plagioclase, pale or colourless monoclinic pyroxene, and dark red-brown or green hornblende. Occasionally they carry irregular 2 mm. blastoporphyritic crystals of olivine that are traversed by cracks or fissures along which abundant opaque ore has been deposited. These rocks must represent a distinctly high grade of metamorphic change, and they are to be regarded as recrystallized dolerites and gabbros. It is possible to make this statement with entire assurance as, not infrequently, the remains of doleritic or gabbroic texture can be clearly discerned. Several of the thin slices show an abundant subsequent veining of the masses by analcite and prehnite, and not uncommonly the whole plagioclasic part is observed to be pseudomorphed by albite, or replaced by obscure opaque saussurite. Other masses in the eastern area include ophitic olivine-dolerites, some of which afford little indication of thermal change save a clouding of the primary plagioclase. And there are also rocks of similar texture that have been amphibolized, and have had their felspar partly recrystallized and replaced at a later time by albite and prehnite. Evidence of powerful shearing is occasionally to be observed, as in an interesting gabbro near the head of Poundland Burn, and some of the rocks have been reconstructed with a distinct mineral banding, a feature long ago observed by Sir Jethro Teall. It is necessary to add that there is no discernible grouping or arrangement of types within the area under discussion.

West of the Garnaburn–Lendalfoot road, the rocks are of equal interest and afford examples of sheared and unsheared thermally altered dolerites and gabbros. To the south and south-east of Balhamie Hill excellent unsheared olivine-free dolerites can be seen, which are 1 mm. ophitic plagioclase-pyroxene rocks carrying a little titaniferous ore. The only evidence these rocks provide of thermal alteration is the clouding of their felspars, although occasionally, as in one of the masses to the north of the cottage known as High Balhamie, a curious irregular rodding is seen in the monoclinic pyroxene, as if some process of dissolution had affected the mineral along its cleavage separation planes. The Cloven Rocks, at the north-west corner of Balhamie Plantation, consist of unsheared ophitic dolerite, showing cloudy or schillered and saussuritic felspar and carrying colourless pyroxene altering to a pale or bright green hornblende. One thin dyke within the boundary of the plantation is a beautiful ophitic dolerite with colourless or pale brown monoclinic pyroxene, passing into pale brown hornblende, and schillered felspar. Granules of olivine occur abundantly in this rock, which, it should be pointed out, strikingly recalls some of the black dykes on the shore at Coverack, in the Lizard.

Rocks within the western area that have been altered in a considerably greater degree than the above are seen on the moor to the east and west of Balhamie. Many of them exhibit in beautiful manner the transition from a true doleritic to a crystalloblastic texture. The relict felspars are always schillered or clouded, and the new granular felspar is usually water-clear and associated with granules of hornblende and pyroxene, and flakes and plates of orange-red biotite. Occasionally the rocks are holo-granulites exhibiting no evidence of their doleritic origin. Nearly all of them are traversed by veins of albite and analcite, which substances at the same time have extensively replaced the felspathic content of the masses. The well-known rock of Bougang, two miles west of Colmonell, shows schillered and distorted relict phenocrysts of soda-lime felspar in a recrystallized granular ground of similar substance and green-brown hornblende. The large crystals are in process of reconstruction and are strewn with granules and aggregates of granules of hornblende and orange biotite. The scapolite-bearing rock formerly noted (D.B. 1932) has been determined as the mega-crystalline veining of a fine-grained ophitic dolerite, which has been thermally altered and probably pneumatolyzed. It likewise affords evidence of a generous subsequent introduction of analcite and albite.

When shearing has affected the above rocks they pass into hornblende-schists, or plagioclase-amphibolites, often carrying an abundance of biotite. It is not possible to refer here to all the occurrences that have been found in the hill country to the north and west of Colmonell. One of the most interesting exposures is that laid bare to the east of the summit of Balhamie Hill, about 400 yards due north of Deafstone (which is situated 700 yards north-west of Colmonell). Specimens from this exposure were described by Sir Jethro Teall (*Sil. Mem.*, p. 479) as " too fine in grain for precise determination, but apparently it is a foliated rock, composed essentially of small grains of brown hornblende and altered felspar. It is a rock . . . in which shearing has affected the entire mass ". On the 6-in. maps of H.M. Geological Survey the outcrop is indicated as " thermally altered lava ". Recent examination of this mass, which I call " Teall's Granulite ", shows that probably what we have here is a sheared and thermally altered ophitic dolerite, now in the condition of hornblende-schist. Two sets of earth movement have affected the mass. The first has superinduced a flaser structure the structural planes of which strike north-west. The trend of the later foliation is north-east and south-west, and it cuts off abruptly all evidence of the earlier tectonic impress. The felspathic content of the rock has in large measure been pseudomorphed by albite and analcite, and sometimes much biotite can be observed in the sections.

In my former paper I noted briefly how many of the above rocks are intersected by veins of granite and albitite. Continued investigation has demonstrated a more widespread occurrence of these leucocratic materials than formerly suspected. A short distance to the east of Teall's Granulite is an outcrop of amphibolized metamorphosed dolerite, veined by albite-biotite-syenite, showing crushing or protoclastic structure. Also, in the field to the west of the same reference station, a small boss of similar material protrudes out of the serpentine without disclosing any boundaries. It is, however, in the country immediately adjacent to Garnaburn that we find the best examples of these acid intrusives. That they are of a later date than the basic masses with which they are in association is abundantly clear. One knoll on the west side of the stream, about 800 yards north of Garnaburn farmhouse, consists of albitite which has undergone a curious irregular silicification. Another knoll, a few yards distant, shows fine protoclastic albitite, with translucent albitic substance repairing and restoring the earlier broken crystalline individuals of the mass. Nearly all of these albite-rich rocks carry brown biotite, green hornblende, and orthite, not, however, in considerable amount. An interesting exposure occurs on the moor less than three-quarters of a mile to the north-east of Garnaburn farm, where protoclastic albite-oligoclase-biotite-rock invades a contact-altered, or contact alters and invades, amphibolized gabbro, forming a curious mixed rock in which both components have suffered from the effects of shearing.

It remains now to investigate the manner in which the above dolerites and gabbros have acquired their metamorphic complexion. Some of the masses are veined by granitic and syenitic leucocratic material. Considered, on the one hand, as xenoliths in the serpentine, either they have been (1) altered before inclusion in the peridotite, (2) hornfelsed by the peridotite, or (3) altered after inclusion in the peridotite. On the other hand, if the masses be considered as independent intrusions (not xenoliths) in the peridotite, then we can only presume, as for (3) above, that a subsequent metamorphism affords the correct explanation of their present state. Now we might proceed, quite permissibly, to deliberate the arguments in favour of or against the foregoing possibilities—to debate, for instance, how sometimes it may be observed that masses of small bulk are relatively little altered, which seems, indeed, a curious fact upon any xenolithic hypothesis. But, fortunately, there is one clear section, the evidence furnished by which renders discussion unnecessary. About 600 yards north of Garnaburn farmhouse (at the mark B.M. 230·1 on the 6-in. map) a gateway crosses the Lendalfoot road, immediately to the south-west of which, in the stream, a doleritic rock can be seen branching intrusively in the serpentine, but which, nevertheless, is in a thoroughly metamorphic condition. We are bound to conclude here that alteration after emplacement affords the correct interpretation of the history of this mass, which, it must be pointed out, is quite a characteristic member of the metamorphic suite described above. The unaltered character of the contiguous serpentine is at once apparent, but can easily be accounted for if we recognize a relatively late date for the process of hydration of the peridotite.

From the position thus attained we advance to a recognition of the fact that the whole southern belt of the Ballantrae peridotite and its accompanying intrusions must at some period have been subjected to contact thermal, or regional, metamorphism. The granitic and syenitic veinings, and the abundant secondary genesis of biotite in many of the altered rocks, suggest proximity to some large uncovered acid intrusive mass. To one, however, who has worked in the Lizard district of Cornwall, or who has read the accurate descriptions by Sir John Flett in the Lizard Memoir, there is no difficulty in correlating some of the altered and recrystallized Ballantrae dolerites with the black dykes of that region, which exhibit a range of metamorphic phenomena compassing nearly all that can be seen at Ballantrae. Among the hypabyssal intrusives of the latter region, however, we not infrequently discern the results of a more intense degree of thermal change, and the process of analcitization, which is a common feature in the Ballantrae metamorphic rocks, is apparently unknown in the Lizard. But the capricious distribution of the different types, in the respective areas, exhibits a remarkable correspondence. Thus at Manacles Point, east of St. Keverne, there occur thermally altered black dykes, intersecting thermally altered gabbro, agreeing precisely with what can be seen in a small quarry on the Pinwherry–Colmonell road at Garnaburn. The conclusion I reach is that in Ballantrae we are presented, as in the Lizard, with the remnant of a more extended province, that has been the theatre of subterraneous igneous activity many times renewed and of repeated metamorphisms in which heat and directed pressure have been concerned in fluctuating association. In the Lizard we are not able to say how much of the thermal metamorphism should be attributed to the late acid gneiss, or if the process of serpentinization followed hard upon the injection of that component of the complex. And, likewise, in Ballantrae it is not yet possible to determine positively in what degree an uncovered granitic or syenitic intrusion should be held responsible for the visible metamorphism.

II. Replacement Granites and Crush Rocks.

In my former paper (Geol. Mag., 1932) reference was made to the occurrence, upon the north face of Knockormal Hill, of a curious granitic rock, the felspathic content of which had been largely corroded and replaced by quartz. In the present note I propose to record the discovery of some other rocks of similar type, and to describe briefly the interesting masses with which they have been ascertained to be associated in the field.

If the coloured 1 inch to the mile map of Scotland, Sheet 7, be consulted, it will be observed that from Garnaburn, east of Colmonell, there extends for about 4 miles north-eastwards a broadening belt of territory represented in a pale carmine. The explanation at the side of the map conveys the information " contemporaneous diabase ". The country under notice lies between the River Stinchar and the southern boundary of the serpentine, stretching south-west from Millenderdale. A large part of it ascends to above the 600 ft. contour, but towards Garnaburn the level sinks, south and west of Prieston Hill, until the moorland road is reached which runs north-west to the coast at Lendalfoot. But not all of the tract referred to consists of "contemporaneous diabase". Between Garnaburn and Poundland Hill there is a considerable development of fragmental material, described in the *Upland Memoir*, p. 453, as consisting of agglomerate and breccia. It is in association with the pyroclastic and igneous rocks here displayed that the new outcrops of granite have been found.

The first exposure may be seen 20 yards south of a prominent rocky knoll, on the hillslope about 700 yards due north of the main Pinwherry Road (on the north side of the River Stinchar), at the milestone indicating 1 mile east of Colmonell. In the field, examination of the grey weathered face shows a thoroughly brecciated condition of the mass. But the majority of the fragments do not seem to have been displaced greatly. The character of the rock suggests, indeed, concussion fracturing. Microscopically it consists usually of albite, epidote, and quartz. But some portions of it show only 1 mm. laths of albite along with a chloritized ferromagnesian, or epidote, and it is probably from spilitic diabases of such mineral construction, or amphibolized and albitized ophitic dolerites, that the granitic rocks of Knockormal Hill and Prieston Hill have been produced by hydrothermal processes. The effects resulting from the introduction of silica, in the form of quartz, can be readily followed. Large 4 mm., or thereby, poikilitic patches of quartz appear, in the midst of which, variously oriented, lie the remnants of corroding and dissolving laths of albite. The quartz areas usually extinguish as crystalline individuals, and sometimes it can be noted that the sections afford the diamond-shaped contours of bipyramidal quartz. In many slides micrographic and myrmekitic developments are shown in great variety, and in nearly every preparation there is a considerable proportion of crush material. Now it is of interest to observe that during the year 1933 there appeared an important dissertation by Mr. James Gilluly, of the United States Geological Survey, on the "Replacement Origin of the Albite Granite near Sparta, Oregon" (*Prof. Paper*, 175–C), in which rocks agreeing very closely with those from Knockormal and Prieston Hill have been carefully described. The conclusion reached by Gilluly is that such micrographic and myrmekitic granites have resulted from a late magmatic and post-magmatic replacement of the almost completely solidified diabase, and that the albitizing and silicifying liquors were in part, or entirely, guided by zones of fracturing and brecciation. A transition series has been identified by him showing how to the accompaniment of a gradual increase in quartz content, the diabases of ordinary type pass into brecciated granites. In the Ballantrae region I have not thus far been able to trace a complete suite of intermediate stages. But over a large extent of the moor on Prieston Hill it can readily be ascertained that many of the spilites and spilitic diabases have been silicified in a diversity of ways, and often with the production of very perfect myrmekitic and graphic structures. And, too, where the granites of Knockormal and Prieston Hill are approached, it can be determined that brecciation of the contiguous rocks is a characteristic feature and that it is possible to pass, in the matter of a few inches, from brecciated quartzose micrographic transformed spilite, or diabase, to a coarse granite showing large pseudoporphyritic quartz-albite-epidote nuclei dispersed in a dark-coloured, obscure, cataclastic ground.

There seems no doubt that these curious rocks have resulted from hydrothermal processes, as inferred by Mr. Gilluly. It is hoped that continued investigation may throw further light upon their obscure petrogeny. Other good exposures of brecciated myrmekitic granite, it may be added, have been recently found 400 yards north-east of the sheep fold above Garnaburn, on the east side of the Lendalfoot Road. Some of the rocks here seen consist of albite and quartz, but others are highly epidotic, and all show evidence of cataclasis. They are environed by blue-grey spilites and diabases, some of which have been micrographically silicified to the virtual extinction of their original character.

The replacement granites, and quartzose spilites and diabases are not the only rocks upon Prieston Hill deserving of study. The fragmental rocks prove to be of not inferior interest. These, as noted, were considered by Drs. Peach and Horne to represent volcanic ash. But the available facts suggest to me a different interpretation. The enclosed fragments and blocks, of wholly irregular contour, consist of ophitic, amphibolized, and albitized diabases, myrmekitic quartz-albite-epidote rocks, albite-chlorite-epidote rocks, quartz-epidote rocks, or epidosites, sub-variolitic spilites and fragments of obscure material, probably of sedimentary origin. The ground or base in which the blocks and fragments are enclosed cannot in many cases be resolved, being turbid with chlorite, epidote, and sphene, and crowded with broken and comminuted felsic and ferro-magnesian minerals. Some of the epidosites are very interesting. They have manifestly resulted from replacement processes. Epidote has partly taken the place of the original plagioclase, probably as the result of an initial process of albitization, and subsequently quartz has replaced the soda-felspar. Hence we trace a transition from normal diabase to epidote-quartz rocks, in which finally a mosaic of irregular quartz plates is strewn with reddish-brown usually turbid epidote. The myrmekitic rock fragments also merit careful examination. The range of grain size and texture among them is remarkable, extending from very fine-grained rocks, that mineralogically resemble micrographic quartz-felsites or keratophyres, to coarse-grained granitic rocks that cannot be distinguished from the replacement granites above described. In some of the fine-grained felsitic-looking rocks occur porphyroblasts of bipyramidal quartz fringed with myrmekite. The inference that the inset crystals are of secondary character is founded upon the fact that often the diamond-shaped sections can be seen enclosing the dissolving remnants of crystalline albite. The locality where the fragmental rocks can best be investigated occurs due north of the milestone referred to above, and about 30 yards north of the Craig Plantation, which borders the ground rising immediately above the alluvial flat of the River Stinchar.

Forty yards to the south-west of the first-noted outcrop of replacement granite, on Prieston Hill, there occurs a large flinty or chalcedonic reef. The substance of this reef was thought by Drs. Peach and Horne to consist of radiolarian chert. Microscopically it closely resembles some of the sideritic cherts described in the Monographs of the Lake Superior iron-producing regions, and there does not appear to be any evidence that it is of organic origin. More probably it is a hydrothermal product connected in some way with a great crush-zone that I believe to have a north-east – south-west extension along the southern flank of Prieston Hill. The sheet planes of this crush-zone have locally parted, affording an extensive lenticular exposure of the intervening crush material. It is this cataclastic aggregate of hydrothermally altered rocks, adverted to in the previous paragraph, that was considered by Drs. Peach and Horne to represent volcanic ash and agglomerate. If my own assumption be correct, then it is easy to understand how, within a short distance in the field, we see one and the same rock—the replacement granite—brecciated *in situ* and also occurring as broken fragments in a mixed breccia.

More or less parallel with the Prieston Hill crush-zone there is probably another line of movement, with concomitant crushing, striking north-east from Knockormal. In the field north of the eclogite – glaucophane-schist ridge, referred to in the last section of this paper, there is an exposure of red chert with adjacent silicified spilite. It is in juxta-position to this more northerly crush-belt that the Knockormal replacement granite has been generated.

Referring to the rocks of Prieston Hill, there is one other outstanding matter that it is necessary to mention. In the Benan Conglomerate, widely exposed over the whole Ballantrae region, there may be found along with boulders of spilite and serpentine (common in the channel of Pinjerroch Burn) a great variety of contact-altered dolerites and gabbros. But with these there occur boulders of replacement granite and hydrothermally reconstructed diabases and spilites. Thus at Kennedy's Pass, Drumfairn, Knockbain, and elsewhere, there have been recorded myrmekitic granites, epidosites, and felsitic and keratophyric rocks, closely resembling types that can be collected on Prieston Hill. Thus the development of the crush zones must have been completed prior to the deposition of the Barr Series.

III. AGE RELATIONS OF THE BALLANTRAE IGNEOUS COMPLEX.

In the past various opinions have been expressed bearing upon the age relations of the igneous components that build the Ballantrae region. Professor Bonney (*Q.J.G.S.*, 34, 1878, 784) thought that the porphyrites and diabase porphyrites were "probably outliers of one or more great lava sheets, and no doubt like others in that part of Scotland, of Old Red Sandstone (probable Middle) age". The serpentine, he regarded, as "later than the porphyrite tuffs", and the diallage rock of Lendalfoot still more recent; both intrusive members possibly being referable to the Carboniferous.

The discovery by Charles Lapworth (GEOL. MAG., 1889, 20) of a Middle Arenig fauna in shales intimately associated with bedded volcanic ashes on the shore at Bennane Head inaugurated a period of more precise knowledge. It may be recalled that Lapworth, in the paper containing that important announcement, expressed the belief that the diabases, syenites, gabbros, and serpentine must be of post-Girvan date, and thus clearly were to be separated from the contemporaneous volcanic rocks, the age of which he had definitely ascertained.

Following Lapworth in a certain measure Drs. Peach and Horne also thought that the ultra-basic and basic rocks pierced the lavas and agglomerates, and therefore should be considered as of a younger age. They concluded, however, that the serpentine, gabbros, and diabases represented the plutonic and hypabyssal members of the Arenig igneous cycle and essentially that is the substance of the narrative conveyed in the *Upland Memoir*.

But, subsequently to the appearance of the official publication, not more than ten or twelve years had elapsed before Peach explained to me that out of the recollection of his many careful traverses in South Ayrshire he had inferred the possibility of a pre-Cambrian age-reference for the Ballantrae serpentine and some of the associated gabbros. He held in memory the intimate contact between serpentine and black shale at Pinbain, but was cognisant of the fact that here might be merely one of those not infrequent instances in the course of geological investigation where, notwithstanding clear field exposure, there is difficulty in interpreting the evidence.

Peach's modified view was well known to most of his colleagues, and at the time referred to it was vigorously expounded by his friend, Mr. Arthur Macconochie. Lately it has been resuscitated by Dr. J. Pringle, of H.M. Geological Survey, whose most helpful and perhaps best-informed adversion is that in which he refers to Dr. Cowper Reed's researches on the Girvan district trilobites, and the bearing of these researches upon the matter of Ordovician physiography (*Proc. Geol. Assoc.*, xliv, 1933, 57).

Now these remarks are only accessory to an explanation of the fact that lately I have discovered, as I believe, real evidence having a direct contingency upon this question of the geological age of the Ballantrae serpentine-gabbro complex. In my 1932 paper, it was indicated how the finding of gabbro blocks in volcanic ash and agglomerate at Pinbain and near South Ballaird prescribed the need for further field investigation, and the opinion was expressed that ultimately it might be possible to present a new interpretation of the geological history of the area. Since 1932, therefore, I have devoted whatever time I could to a re-scrutiny of the rocks over the whole region, and I now adduce certain additional considerations that lend justification to that statement.

Firstly there is the curious and perplexing fact that over a large extent of the Ballantrae region the serpentine shows a north or north-west foliation. This foliation does not appear to have been commented upon by any previous writer. It is admirably displayed at Gamesloup, on Balhamie Hill, on the hill to the north-west of Laigh Knocklauch (D.B. 1932), and elsewhere. On the shore, south of Burnfoot, it can be seen inclining at a high angle inland and striking directly at an upstanding wall of crushed spilite. Nowhere over the whole province is it to be recorded that the effusive rocks have acquired a north-west superinduced structure. The conclusion pointed to is that the observed foliation is of an older date than the eruptive discharge of the lavas. The contacts of the serpentine with the Arenig rocks are generally puzzling, although sometimes they are clearly structural boundaries. Thus, at the head of the Poundland Burn quite unaltered lavas are exposed, but a few feet distant from highly recrystallized pyroxenic and amphibolic granulites lying within the serpentine area. A similar disposition of matters can be demonstrated at other localities. Upon the south face of Moak Hill the contact is clear, and is probably a thrust plane dipping to the north-west. Likewise the rocky south face of Knockdaw Hill adjoins a tectonic line. Upon the roadside running up the north bank of the Bennane Burn there is an interesting junction, where highly flasered and crushed serpentine makes contact with greatly chloritized ash and diabase; the flaser planes of the serpentine striking obliquely at the boundary. At Pinbain the evidence is difficult to understand, but after careful investigation I can only say that I have failed to convince myself of any simple intrusive interpretation of the serpentine. On the other hand, indications of considerable crushing can be readily discerned.

Now the above facts may perhaps not of themselves carry much weight of conviction, but there has lately been found important contributory evidence. About 450 yards due north of the farm of Knockormal, which lies on the moor approximately 1 mile S.S.E. of Lendalfoot Bridge, there can be observed a ridge of cultivated ground which contrasts markedly with the sheep pasture to the south. This ridge, indicated on the Geological Survey 1-inch map as consisting of gabbro and serpentine, stretches due east for about 600 yards, and it exhibits some of the most interesting rocks that have yet been discovered in the Ballantrae region. At the east end occurs a large knoll of foliated hornblendite and smaragdite-eclogite. The foliation is towards the north-west. The grain size of the materials here exposed ranges up to about 2 cm. The rocks are of a dark-green colour, and they carry lenses and streaks, or disseminations, of pink garnet. Microscopically they have been ascertained to consist of smaragdite; smaragdite and clino-pyroxene; smaragdite and garnet; smaragdite, clino-pyroxene, and garnet; and smaragdite, clino-pyroxene, garnet, and green spinel. The pleochroism of the hornblende is (α) nearly colourless, (β) chlorophyll green, and (γ) emerald green or blue-green. The indices of refraction range from 1·65 to 1·66 and the axial angle 2V is close to the value 90°. The pyroxene is colourless or pale green in thin section, is traversed by a close, sometimes fibrous, parting parallel to the second pinacoid, has an angle $2V = 55°–58°$, and shows an extinction $c : (\gamma) = 43°$ or 45°. Determination of the density of the garnet which is traversed by groups of parallel cracks, as usual in the eclogites, yielded a value = 3·75, and the refractive index in yellow light is 1·752. The texture of the eclogite is xenomorphic or xenoblastic. Some specimens are distinctly foliated, but others do not show any tendency to fracture more readily in one direction. In those specimens showing a pronounced parallel structure it can be seen that the crystal axes c of the amphibole are lying approximately in the same bearing. Enclosed in the hornblende lie numerous rounded and embayed fragments of garnet, clino-pyroxene, and brilliant green spinel. The last noted occurs in plates up to 0·8 cm. in cross section, and these are usually bordered by obscure, rusty, hematitic or limonitic, serpentinous substance. The mineral is occasionally traversed by intersecting groups of lines of dark material probably rich in iron ore, and it also encloses innumerable fragments of a colourless undetermined accessory showing faint blue pleochroism. This minor constituent has a high double refraction, and therefore cannot be sapphire.

In many respects the eclogites from near Knockormal resemble some of those described by Professor Eskola from the cape west of Gangeskar, Selje, Nordfjord.[1] Writing of the Gangeskar eclogite Eskola says: "The pyroxene and garnet both present themselves as relics and the development of the rock probably was somewhat as follows: Garnet and ortho- and clinopyroxene had crystallized out from the magma in the usual way, but the consolidation did not end with these phases, probably because mineralizers were present in larger amounts than usually and residual magma was still present, when the temperature had sunk below the stability limit of the eclogite facies. The clinoamphibole then began to crystallize and, at the same time, resorption of the pyroxene and, though in smaller degree, of garnet set in."

At the west end of the ridge, about one hundred yards east of the

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[1] I should like to acknowledge with gratitude the services of Dr. Oftedahl, of the Museum of Oslo, who kindly obtained and sent to me specimens of Professor Eskola's type eclogites from the Gangeskar region of Nordfjord.

Lendalfoot Road, north-west foliated epidote-hornblendites and garnetiferous glaucophane-schists are exposed. It is evident here that the more schistose rocks have been derived from hornblendites of doleritic grain-size to the accompaniment of shearing. In the field the hornblendites possess a marked parallel structure, the planes of easy fracture showing the lustrous cleaved faces of green hornblende and honey-yellow epidote. The glaucophane-schists, interbanded in the hornblendites, are greenish-blue rocks, exceedingly tough under the hammer, and possessed of a fine silky sheen, and sometimes a curious rippled fracture. The correspondence with some of the Anglesey rocks described by Dr. Greenly (*Mem. Geol. Surv. Anglesey*, vol. i) seems to be very close, although garnet does not appear to have been noted in the Welsh occurrences. The hornblendites and schists near Knockormal are intersected by transverse veins of albite and by lines of intense crushing. Thus one may collect much material that exhibits only a cataclastic texture. The explanation of this I attribute to proximity to one of the great post-Arenig crush lines that ranges from Knockormal towards Knockdaw Castle.

Under the microscope the hornblendites are seen to consist essentially of green amphibole and epidote. The amphibole, of 2 mm. grain size and in many sections equidimensionally developed, is pleochroic according to the scheme (α) pale yellow, (β) dark leaf-green, and (γ) pale blue-green or bronze-green. Often the crystals pass marginally into glaucophane of characteristic blue-violet colour, the extinctions changing in accordance with a change in composition. Enclosed in the hornblendic web, as inclusions in individual crystals or in the interspaces, lie numerous 1 mm. prisms of colourless or pale yellowish-brown epidote. The growth is along the monoclinic ortho-axis and there is a tendency to idiomorphic development. Numerous little brown spindles of sphene are strewn over the sections, and patches and veins of albite and prehnite are usually present, often in association with zones of crushing and obscure crushed material. In appropriate sections it is apparent that the hornblende crystals have formed with parallel alignment of their *c* axes.

The finer grained glaucophane-schists are interesting rocks and, like the Anglesey schists, consist " of a continuous foliated weft of clear blue glaucophane, in which float the epidote and all the other minerals " (*Anglesey Mem.*, vol. i, 115). The glaucophane occurs in narrow 0·2 mm. prisms elongated along the third axis. Favourable sections show the characteristic amphibole cleavage. The pleochroism is (α) pale yellow or nearly colourless, (β) lavender or violet, (γ) violet or sky blue. The extinction $c : (\gamma)$ may amount to 8° but is difficult to determine accurately. The 0·5 mm. epidote prisms are developed along the *b* axis and often show a broken or beaded appearance. The mineral is yellowish in colour and is sometimes clear, although very often turbid or dusty from obscure included matter. Much dark sphene may be detected in the sections. Garnet occurs somewhat rarely as 0·3 mm. equidimensional idiomorphs, which are traversed by rectangular cracks that are not continued beyond the boundaries of the crystals. Occasional clear patches and veinlets may be quartz, and there are frequent transverse stringers of albite and crushed material. A rucking or rippling of the foliation is sometimes discernible in sections cut normally to the structural planes.

Now the interest of the above rocks lies in the fact that they must have crystallized, or have been reconstructed, under physical conditions of a special type (see Harker's *Metamorphism*, 307). As they are interbanded along with the older environing serpentine they must also clearly indicate something of the plutonic or regional metamorphic history of that great component of the igneous complex. The question therefore may be cogently asked—how is it possible for the spilitic lavas into which the serpentine is supposedly intrusive to have remained everywhere unmetamorphosed, save for the process of albitization ? By this manner of reasoning I reach the conclusion that the serpentine, eclogites, glaucophane-schists, and many of the gabbros and metamorphosed hypabyssal intrusives are of higher antiquity than the Arenig lavas.

Referring now to the occurrence formerly noted (1932) of disrupted blocks of gabbro in some of the Arenig agglomerates, the following are the results, briefly stated, obtained from continued investigation along that line of inquiry. The facts emerging seem to authenticate the validity of the inference stated above.

The most interesting and instructive exposure to which attention may be directed is that situated 600 yards to the east of the farm of South Ballaird, where the fragmental rock builds a prominent knoll. The substance of the mass has been quarried in old days for the construction of the neighbouring stone fences, and many rudely fashioned blocks taken from it can be seen built into the field boundary walls (as in that immediately east of the knoll). From material collected here, *in situ*, there have been identified amphibolized gabbros, "granulitic gabbros," hornblende pyroxene granulites, plagioclase-amphibolites, thermally altered and sheared dolerites, serpentinous fragments, and numerous spilites—some finely glassy or variolitic, and others showing their characteristic purple pyroxene unaltered. What, in fact, we determine is a mixture of metamorphic and non-metamorphic rocks. Many of the former correspond to types seen within the serpentine area immediately to the south. Here, therefore, is surely provided helpful geological evidence. Whether the fragmental material is of clastic or pyroclastic origin, it seems fairly obvious that near South Ballaird we must be dealing partly with the relics of some pre-existing crystalline floor that had undergone sub-aerial degradation in Arenig time, or had been disrupted by the spilitic volcanic forces. In this way are we again led to the contemplation of an older date for the serpentine and associated rocks.

[Since the above notes were assembled for publication there has appeared, in a recent issue of the GEOLOGICAL MAGAZINE (Dec., 1936), a paper by Dr. J. G. C. Anderson on the Age of the Girvan–Ballantrae Serpentine. In this communication Dr. Anderson, evidently founding upon the evidence furnished by a microscopic preparation, claims that the serpentine, exposed on the shore at Pinbain, exhibits natural intrusive junctions against spilitic lava. I have always considered it extraordinarily difficult to understand how the serpentine could possibly be intruded to this stratigraphic level and, thereafter, have experienced a high grade of metamorphism and acquired a north or north-west foliation, no traces of either of which are ever to be detected in the rocks of demonstrable Arenig age. If Dr. Anderson can explicate this puzzling matter he will make, indeed, a noteworthy contribution to the geology of the Ballantrae region.]

On *Camarotoechia borealis* (von Buch 1834, ex. Schlotheim 1832).

By J. K. S. ST. JOSEPH, Sedgwick Museum, Cambridge.

HISTORY AND INTRODUCTION.

THE name of this species was proposed by Schlotheim (1832, 65, No. 88), but the history of the form really goes back to Linnaeus. The earlier writers on the Scandinavian Palaeozoic took the name *Anomia plicatella* Linn. (1758, 702) to cover a great number of different ribbed brachiopods, and referred in their synonymies to the form figured in fig. 5, of tab. v, of Linnaeus's *Museum Tessinianum* (1753), a work published some years before the adoption of binomial nomenclature. When different authors began to subdivide this group, the name *plicatella* came to be restricted to a species referable to the genus *Spirifer*, and though some authors, Wahlenberg (1821, 67) and Dalman (1828, 140, Tab. vi, fig. 2), continued to use the name *plicatella* in a wide sense, so as to include the species under consideration, the latter seems to have come within the range of forms described by Schlotheim (1813, 36) as *Terebratulithes lacunosus*. This author apparently had the intention of separating a group of ribbed Silurian brachiopods, under the name of *Terebratula borealis*, for in the catalogue of his collection (Schlotheim, 1832, 65, No. 88) six specimens from the "Uebergangskalkstein" of Sweden are entered under this title. The term, however, remained a *nomen nudum* until von Buch (1834) gave an adequate description, and it is to this author that the species should correctly be ascribed. He chose as type a specimen from the *Encriniten-Übergangskalkstein* of Gotland, figured in an earlier work by Schlotheim (1822, 68, Taf. xx, fig. 6*a–c*) as *Anomia Terebrat. lacunosus*. Von Buch was evidently using the stratigraphical name "Übergangskalkstein" as defined by Hisinger (*Anteck. i Phys. ock*

Geogn., etc., iv, 1828), who at that time considered that the lower limestone division in Gotland possibly belonged to the youngest part of the " Transition Formation ". As no defined locality is mentioned it is impossible now to be certain of the exact horizon, but Hisinger's *Encriniten Kalkstein* appears to fall somewhere within the beds now taken to be the equivalent of the Wenlock. Lindström (1861, 349, 352–3), who appears to have been the first to record actual localities in Gotland from which this form was obtained, mentions the Visby group of Lilla Carlsö and Klinteberg, which is approximately a Wenlock horizon. Von Buch's description remained the standard one, until Davidson (1869, 174–7, pl. xxi, figs. 14–20, 24–7 ; 1883, 148–9, pl. x, figs. 25, 25*a*) revised the account of the external characters with particular reference to the British examples of the species.

From 1854 onwards the species is referred consistently to *Rhynchonella*, and it was not until 1894 that a generic subdivision of the Palaeozoic species attributed to that genus was attempted by Hall and Clarke, who proposed the new genus *Camarotoechia* to include forms with a median septum in the dorsal valve, dividing posteriorly to support the hinge plate. As type they chose *Rhynchonella congregata* (Conrad), a Devonian species from the Hamilton Beds, New York. *Rhynchonella borealis* does not seem to have been recorded from America, and was thus not named by the authors of *Camarotoechia* among the species referable to that genus. Subsequent writers have referred the species to *Rhynchonella* and *Camarotoechia* indifferently in spite of the fact that no adequate description of the species appears ever to have been published.

MATERIAL.

The present description of the species is based on the extensive collections of material from Llandovery, Wenlock Shale, and Wenlock Limestone horizons in England and Wales, in the Collections of the British Museum (Natural History) and the Sedgwick Museum, together with specimens collected by the writer from the various inliers in the Welsh borderland. Some of the Rhynchonellids from South Scotland have also been studied, while representative material from the type area in Gotland has been examined in the Naturhistoriska Riksmuseum, Stockholm, and the Palaeontological Institute, Uppsala.

In most of the specimens the shell substance is present, apart from varying degrees of exfoliation. A few specimens preserved in shale have been ground away from the umbones to give serial drawings or transfers, from which enlarged beeswax models have been constructed. Owing to the relatively small size of the species, rather closely spaced drawings are necessary, and intervals of 0·075 to 0·1 mm. have been found suitable for following the changes in the internal structure. Specimens preserved as casts, from the

Llandovery of Haverfordwest and Malvern have been useful in confirming the information obtained from models, and for throwing light on the muscle impressions.

A plaster cast of the type of *Camarotoechia borealis* in Berlin has been obtained, and the identity of British specimens has been established. The systematic position of the species has been determined by an examination of photographs of the types of *Camarotoechia* in the New York State Museum, as well as by a comparison with specimens of *Camarotoechia congregata* from the type area of Eastern New York, in the British Museum (Natural History).

DIAGNOSIS.

Shell biconvex, outline irregularly oval, or even sub-circular. Usually a little wider than long; the greatest width is attained more than half-way anteriorly. Hinge-line curved. A median sinus in the ventral valve and corresponding fold in the dorsal. Surface covered with prominent, sub-angular, radiating plications. Ventral valve considerably less convex than the dorsal, ventral umbo the higher, often projecting over the umbo of the dorsal valve. Pedicle foramen sub-apical (Text-fig. 1), delthyrium partially closed by deltidial plates. Dorsal umbo incurved. Dentition developed; in the ventral valve, blunt teeth supported on short dental plates, articulate with sockets in the dorsal valve on either side of a divided hinge-plate. In the dorsal valve (Text-fig. 4) a short, well-marked median septum, dividing posteriorly to enclose a small crural cavity. Crura flattened, short, divergent.

DISCUSSION.

External Characters.

There is a considerable variation in such external characters as length, breadth, and thickness. This is in part developmental variation depending on the age of the individual, while the variation occurring in normal adult specimens is controlled by the degree to which one or more characters are emphasized in growth. Here only the normal characters of the adult are considered. In outline the two lateral margins of the shell diverge from the umbo at an angle which varies from rather less to rather more than a right angle. There are no true cardinal angles, but the edges of the valves curve round to the anterior margin, which is roughly parallel to the hinge-line. The shell attains its greatest breadth well in the anterior region (commonly about two-thirds of the distance from the posterior to the anterior margin). The breadth is nearly always rather greater than the length. The maximum thickness is attained half-way, or even further towards the anterior margin. It is always considerably less than the length and breadth. The profile is boldly biconvex; the ventral valve is most curved posteriorly below the umbo and anteriorly, the middle portion being flattened. The dorsal valve is the more globose and has stronger curvature.

As the dorsal umbo is usually concealed by the ventral valve, the full curvature of the dorsal valve can only be appreciated when the valves are separated. It is then apparent that in mature specimens the curvature of the dorsal valve, measured from the extreme apex of the umbo to the end of the fold, may be as much as 270°.

The lateral profile, as well as the greatest width, depends very largely on the prominence of the fold and sinus. The latter are always well developed, sometimes so much so as to give the shell a trihedral appearance. There is no inversion of the fold and sinus at different growth stages. The sinus commences rather below the umbo of the ventral valve, and gradually increases in width anteriorly. At the margin it is depressed below the remainder of the valve, where it projects as an angular tongue into the fold of the dorsal valve. The fold commences somewhat beneath the dorsal umbo, and increases in width towards the margin, where it may be considerably elevated above the lateral portion of the valve. The surface of the fold is slightly convex, and its sides are flattened and bent sharply back from the surface so as to appear prominent in profile. Angular or subangular, radiating plications cover almost the entire surface of both valves except for a small area at each lateral margin. They commence at the umbones and increase in prominence anteriorly. Occasional new plications are formed by bifurcation, particularly on the fold and sinus. At the anterior margin there may be from 10 to 19 (typically 12 to 14) plications on each valve, of these 2 to 7 (typically 3 to 4) may lie within the sinus, while 3 to 8 (typically 4 to 5) compose the fold. In detail the margin appears sharply toothed, and each interspace in the ventral valve interlocks with a plication in the dorsal valve and *vice versa*. The plications are formed by corrugations of the valve wall, and appear on internal casts as ridges and troughs.

The surfaces of the valves are also covered by very fine, thread-like, concentric lines, which may mark growth stages; commonly from 6 to 8 occur to the millimetre. The prominence of these lines depends largely on the preservation of the specimen; they are always more easily observed in the interspaces than on the plications.

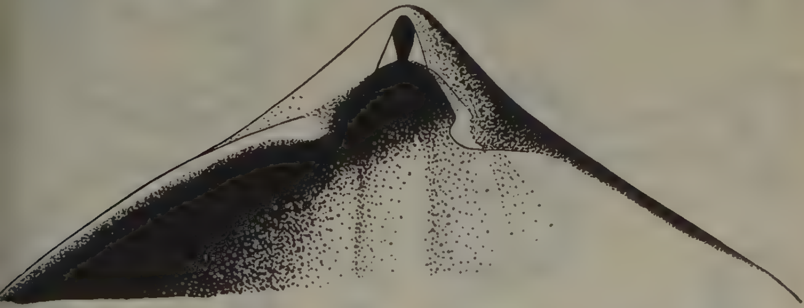
The ventral umbo, which is always the higher, is frequently somewhat acute, and may curve forward to hide the umbo of the dorsal valve. Beneath the umbo is a small triangular delthyrium (Text-fig. 1), partially closed by two narrow deltidial plates, which are not in contact. The delthyrial angle is about 50°. The foramen which is thus margined partly by the edge of the delthyrium and partly by the deltidial plates is small, lozenge-shaped, or sub-circular and never truly apical. In specimens in which the ventral umbo is so incurved as to be in contact with the dorsal valve, the delthyrium and deltidial plates are invisible.

Articulation.

In the ventral valve (Text-figs. 1 and 5) blunt, rounded teeth project dorsally from the commissure to articulate with deep sockets on either side of the hinge-plate in the dorsal valve. The axes of the teeth may be sub-parallel or slightly oblique to the hinge-line. The sockets are deep and well defined (Text-fig. 4), their outer border is formed by the valve wall and their inner wall by the lateral margin of the hinge-plate. There is play only for a limited movement of the valves, and the greater part of the strain in articulation is borne by the hinge-plate.

Internal Characters.

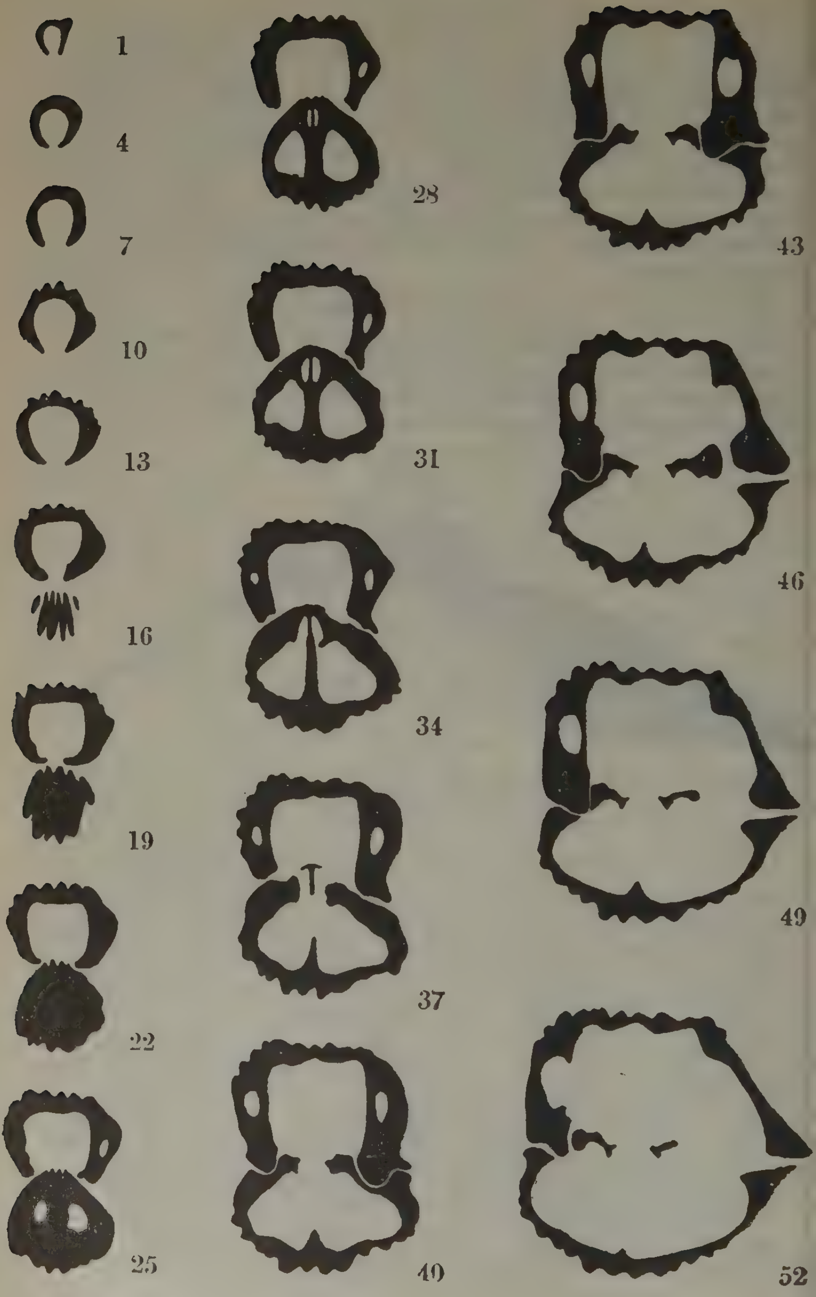
Ventral Valve.—The teeth are supported on very short, sub-triangular dental plates, which are divergent and approximately parallel to the valve wall (Text-fig. 5). Owing to the convexity of the valve, the plates may be quite high. They project backwards from the teeth to the inner surface of the valve, but do not extend below the hinge-line. The cavity enclosed between each dental plate and the valve wall is small, and is partially or wholly filled with a deposit of shell material (cf. Text-figs. 2 and 3). In the latter case the dental plates appear to be fused with the valve wall, but they can be traced as discrete structures by examining the growth-lines in a specimen sectioned at right angles to the length of the shell. Posteriorly the dental plates merge with the valve wall, but the early stages of their development are lost owing to a lack of differentiation of the growth-lines. They do not, however, appear to extend as far as the umbo.

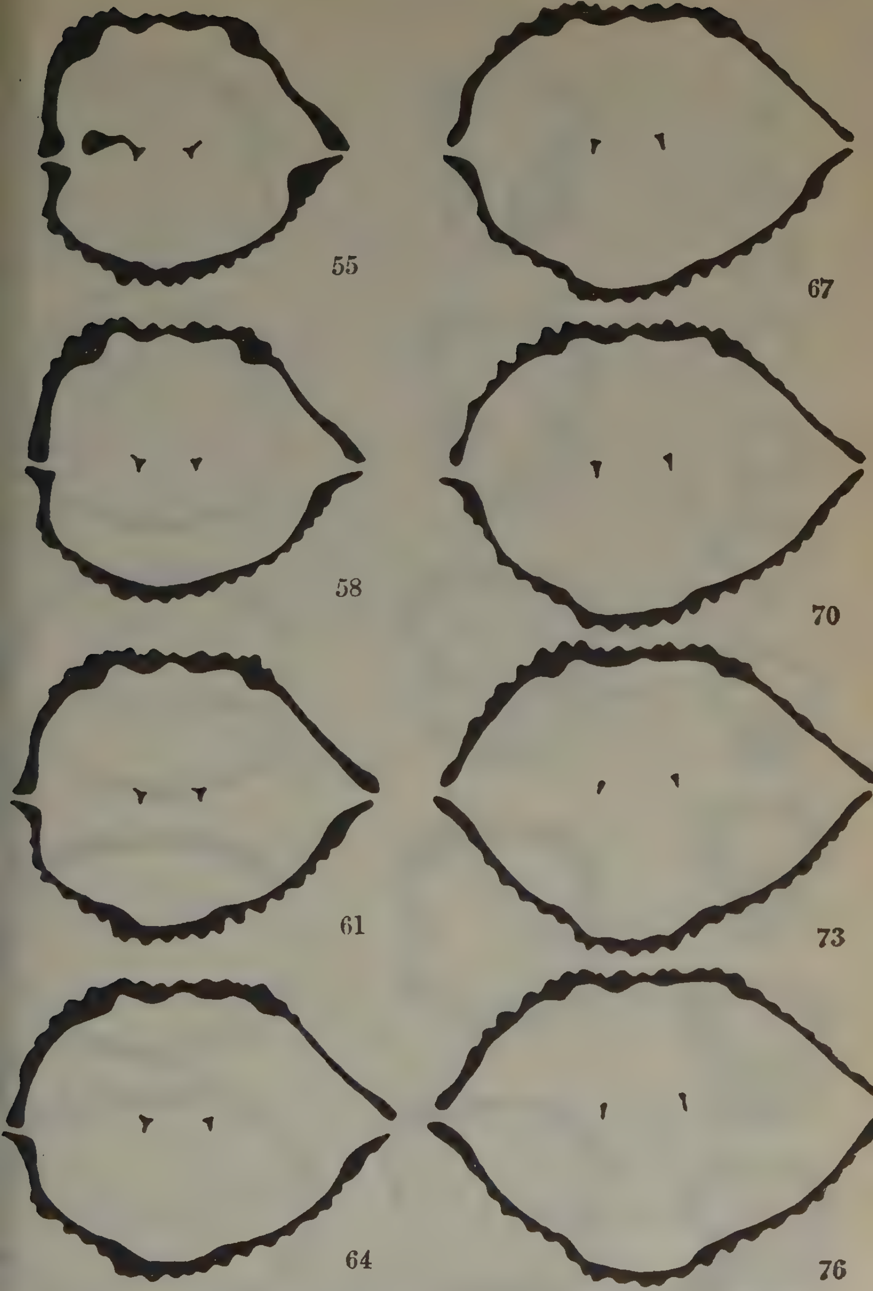


Text-fig. 1.—*Camarotoechia borealis* (v. Buch). Posterior portion of ventral valve, drawn from wax model (Sedgwick Museum, A 8677) of a specimen from the "Wenlock Limestone" of Dudley. × 4.

The dental plates conform to the sides of the sinus, which may begin to develop externally at about the level of the bottom of the plates. In casts the dental plates may be represented by two very short, slightly divergent grooves, on either side of the infilling of the umbonal cavity.

Dorsal Valve.—In the dorsal valve (Text-fig. 4) a simple, short,





TEXT-FIG. 2.—*Camarotoechia borealis* (v. Buch). Serial sections through the posterior end of specimen (Sedgwick Museum A 8677) at 0·075 mm. intervals. × 3. Sections 1–76. (Cf. Text-figs. 1 and 4.)

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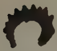
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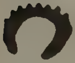
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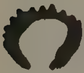
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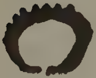
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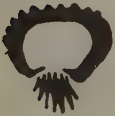
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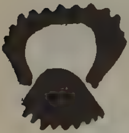
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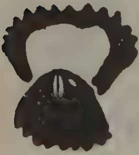
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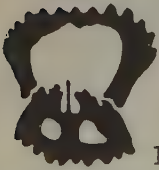
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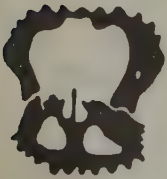
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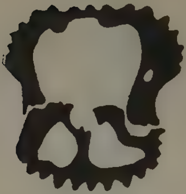
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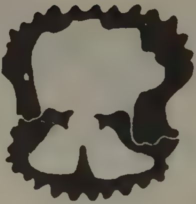
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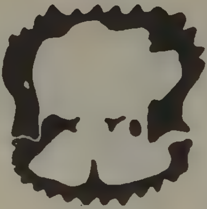
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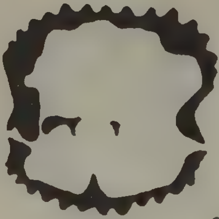
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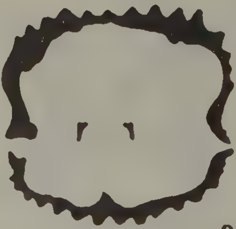
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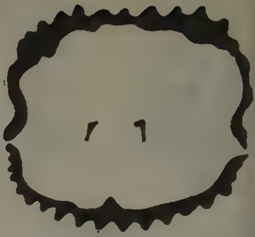
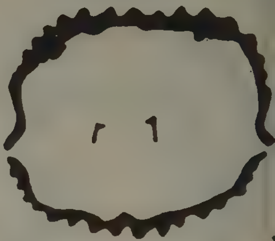
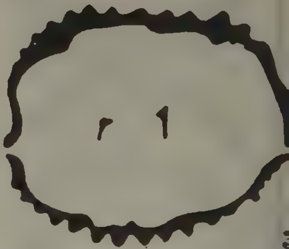
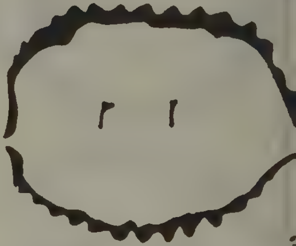
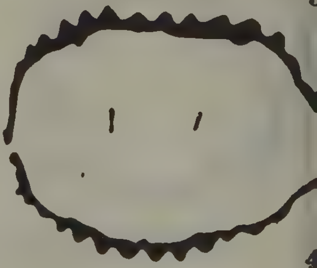


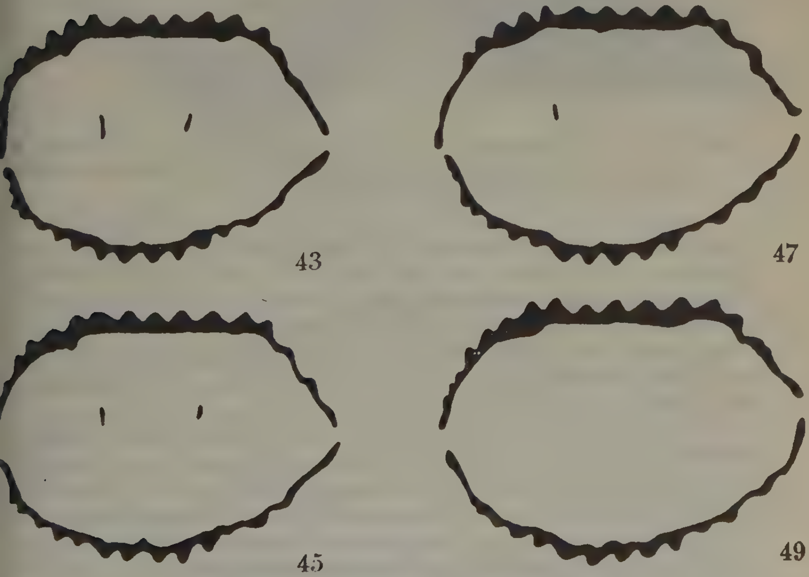








prominent median septum divides posteriorly to enclose a crural cavity, within which is a short, lamelliform central process. In the specimens that have been sectioned, the septum extends up to one-third of the length of the dorsal valve; an examination of casts suggests, however, that it may sometimes be rather longer than this. The interpretation of the structures at the posterior end of this valve is made more difficult by the incurving of the umbo, and the consequent displacement of various structural features. The median septum divides a little below the umbo, each branch of the septum supporting the lower edge of a crural base, which is fused with the inner margin of the hinge-plate. Enclosed between the septum and the inner side of each crural base is a crural cavity, the presence of which entails a division of the hinge-plate. This division of the dorsal septum to support the crural bases is a feature present also in Jurassic Rhynchonellids, and it may be compared with the arrangement present, e.g. in *Septaliphoria arduennense* (Oppel) and *Blockmannella friereni* (Branco), to which Leidhold (*N. Jb. Min. Geol. Paläont.*, xliv, 1921, Beilage Bd., figure on p. 358 and cf. Taf. v, especially figures 2*d*, 3*d*, and 4*b*) has applied the term " septalium ". A very small, flattened plate occurs centrally within the crural cavity in the continuation of the plane of the median septum (cf. Text-figs. 4 and 5 and Sedg. Mus. A 9482). This plate extends from

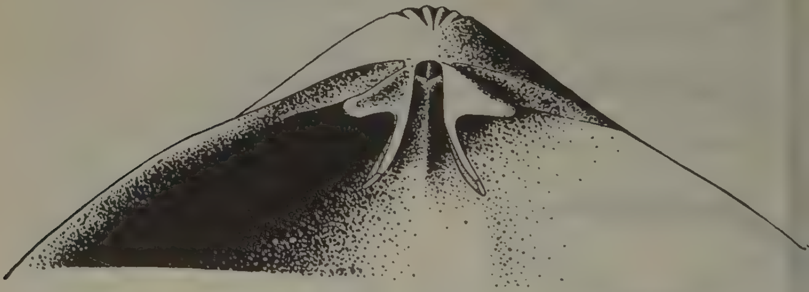


Text-fig. 3.—*Camarotoechia borealis* (v. Buch). Serial transfers (Sedgwick Museum, A 8676 *a–c*) from the posterior end of a specimen, at 0·1 mm. intervals. × 3. Transfers 1–49. (Cf. Text-figs. 1 and 4.)

the base of the crural cavity to the umbo, it occupies the position of a cardinal process. On either side of the median septum a cavity extends posteriorly beneath the hinge-plate ; it may be partially filled by secondary shell substance, though the extent of deposition of secondary shell material in the dorsal valve is usually limited.

The hinge-plate is small and composed of two halves (Text-fig. 4). Each half curves anteriorly from the umbo, its inner edge is formed by a crural base, defining the side of the crural cavity, its outer edge forms the inner buttress wall of a socket, and curves sharply back to join the valve wall. The antero-lateral corner of the hinge-plate may be expanded to afford additional purchase for the teeth.

The crural bases arise below the umbo on either side of the crural cavity, where the growth lines reveal that they are triangular in section. They are slightly divergent and separate from the hinge-plate at the level of the lower ends of the sockets, as two flattened crura, curving antero-dorsally (Text-figs. 2 to 5). In the specimens that have been examined the crura extend for about a quarter of the length of the dorsal valve, and project forward towards the cavity of the ventral valve. The crura consist of a thin band, the upper edge of which is slightly flattened to form a flange, continuing the curvature of the hinge-plate. The ends of the crura may be somewhat expanded.



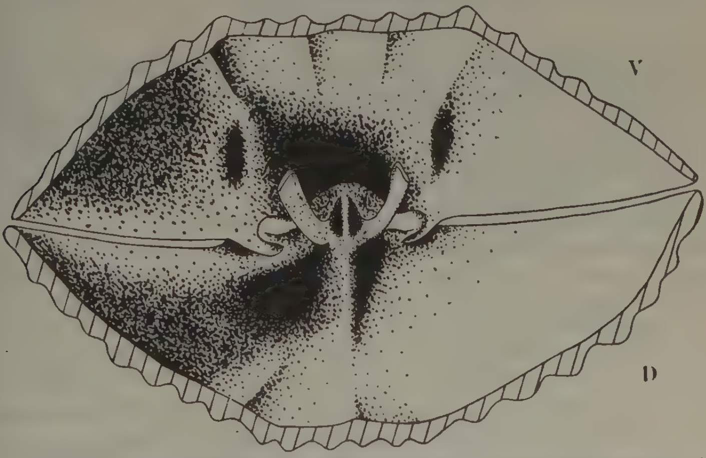
TEXT-FIG. 4.—*Camarotoechia borealis* (v. Buch). Posterior portion of dorsal valve, drawn from wax model (Sedgwick Museum A 8677) of a specimen from the " Wenlock Limestone " of Dudley. × 4.

In casts of the dorsal valve a prominent, short, shallow median furrow marks the position of the septum, and is not to be confused with the hollows between the plications. Above this a small rounded projection forms the cast of the crural cavity, while in a fine-grained matrix this is divided by an extremely narrow, central furrow, indicating the presence of the median lamella plate. (This is well seen in two specimens in the Sedgwick Museum : A 8730 from Malvern, A 8728 from Haverfordwest.) A depressed region on each side of the crural cavity indicates the position of the hinge-plate.

Musculature.

In the ventral valve the points of attachment of muscles form sunken areas on the inner valve surface; in the dorsal valve the area of attachment is less distinct. The muscle impressions, in the ventral valve, may be divided into a median depressed region, lying above and between two lateral areas (cf. Text-figs. 2 and 3, sections 37 to 76 and 21 to 41 respectively, and specimen Sedg. Mus. A 9482). There has evidently been a considerable amount of secondary shell deposition in the neighbourhood of the muscle scars.

The interpretation of the muscle impressions is best attempted by studying the two valves in apposition, as it is only then possible to appreciate the true relations between the various structural elements. With the valves in the position of life, the crura are seen to project well forward into the cavity of the ventral valve (Text-fig. 5). The muscles from the central muscular impression in that valve, which are the adductors, must consequently have passed partly between the crura. The lateral impressions are those of the divaricators, and these muscles must have been attached to the inner surface of the dorsal valve posterior to the hinge-line, and the only region of the shell to which attachment is possible under these conditions is that within the crural cavity, where it seems likely that the small median process divided the two muscle elements. The adductor muscles ran from the median impression in the ventral valve, between the crura to the dorsal valve, where they bedded on either side of the median septum. The exact location of the area of attachment is uncertain; the impressions seem to have formed no real scar on the valve surface, and an examination of models, of



TEXT-FIG. 5.—*Camarotoechia borealis* (v. Buch). Posterior portion of the shell showing the two valves in apposition. × 4. (Cf. Text-figs. 1 and 4.)

casts, and of specimens in which the shell has been burnt off gives in this case little information. That the area of attachment was close to the median septum and well posterior is very likely, for Hall and Clarke's figures of *Camarotoechia congregata* (1894, pl. lvii, figs. 21–4) show in the dorsal valve adductor scars bordering the septum, and in the ventral valve a central grouping of the muscle scars. These authors also note that in a number of species of this genus the muscle scars leave no trace on the inner valve surface.

The muscle impressions in the ventral valve are considerably elongate, and probably represent the growth track of the muscles as well as the actual area of attachment in the adult. The position of the lateral impressions (the divaricators) may be emphasized by a pitting of the surface or by the presence of slightly raised lines, which produce a flabellate appearance.

Development.

A number of progressive changes occur during development. The more apparent changes are those affecting relative dimensions, which produce a consequent variation in outline and profile. In the smallest specimens available for study (about 4 mm. long) the triangularity is more marked, and the outline may approximate to a quadrant of a circle. The profile is gently biconvex, and the two valves are sub-equal in size and convexity. The incipient fold and sinus is distinguishable, while the ventral umbo is very low, only just projecting above the dorsal valve and but little incurved. From this early stage a series of changes leads to the adult condition. The breadth increases relative to the length, but apart from increase in size there is an increase in the convexity of the valves, of the incurving of the umbones, and of the prominence of the fold and sinus. The plications grow in size and angularity, and by occasional bifurcation the number obtaining in the adult is reached.

At the earliest stage that has been examined the delthyrium is not clearly visible and the pedicle opening is sub-apical; almost as soon as a distinct delthyrium is present (at 5–6 mm.) it is margined by two linear deltidial plates. These enlarge with growth, and in maturity they are triangular, extending towards the apex of the delthyrium so as to constrict the aperture to a diamond-shaped or sub-circular opening.

It has not been possible to study in detail the development of the internal characters, though certain general observations may be offered. In the course of growth there is a marked increase in the curvature of the dorsal umbo. This causes a shifting of the area of attachment of the divaricator muscles in the dorsal valve, and also increases the curvature of the hinge-plate and crural lamellae.

Some specimens (Sedgwick Museum A 8678–9) in a fairly early growth stage are preserved with the exterior of the shell dissolved away, and they show clearly the presence of a median septum extending to one-third of the length of the dorsal valve, as well as two short distinct dental plates in the ventral valve. A similar early stage with discrete dental plates may be seen in specimens from Gotland in the Davidson Collection at the British Museum (Natural History) (B 96502–9). The deposition of shell substance between the dental plates and valve wall would seem to occur in the later stages of the life of the animal.

Description of Holotype.

The specimen figured by Schlotheim (1822) as *Anomia Terebrat. lacunosus*, catalogued by him (1832) as *Terebratula borealis*, and later chosen by von Buch (1834) as type, is now in the Geologisch-Paläontologischen Institut and Museum of Berlin University. Examination of a plaster cast (Sedgwick Museum A 8733) shows that the specimen is a fully grown individual of rather large size; in external characters it may be described as typical of the species. The ventral valve is the higher, the dorsal the more convex. The fold in the dorsal valve increases in width anteriorly from the umbo, is high and prominent; the sinus is partially obscured by matrix. The entire surface of the valves, except for a flattened area on each side of the umbo, is covered with angular plications. There are at least 15 plications on the ventral valve and 17 on the dorsal valve. Of these, 5 lie within the sinus while 6 compose the fold.

Dimensions of Typical Specimens (in millimetres).

Length.	*Breadth.*	*Thickness.*	
21·5	25·5	18·4	Present dimensions of type.
21·0	26·8	16·7	
18·8	22·2	17·2	
17·3	23·6	15·4	
16·9	21·1	15·6	
16·4	18·5	13·3	
15·5	17·7	10·0	
15·1	17·0	12·1	
14·4	16·3	12·0	
13·6	16·5	9·8	

DISTRIBUTION AND VARIATION.

Camarotoechia borealis (v. Buch) is a very common fossil in the shelly facies of the Silurian rocks of Great Britain, Scandinavia, and the Baltic Provinces. In Britain it ranges at least from the Upper Llandovery to the Lower Salopian, while its occurrence has been reported in South Wales and in all the inliers of Silurian rocks in the Welsh Borderland. Its presence in the Silurian of Southern Scotland is less well attested, and it is uncertain whether it occurs in the West of Ireland. In Southern Norway the species has been recorded from stages 5 to 8, but it may be that the form in the lower horizons is at least varietally distinct. In Gotland it is very common, and its presence has been noted at many horizons and localities throughout the succession.

No attempt has been made to study in detail the variation that occurs amongst collections of individuals from widely separated localities. A preliminary survey suggests, however, that it is the external characters, such as shape, size, and number of plications that show most random variation. It is noteworthy that the range of the species in space seems to be limited to North-Western Europe. In America, though there appear to be closely allied forms, the presence of *Camarotoechia borealis* has not been reported.

Though there is little evidence for regional variation, one distinct variety may be noted here. The form "*Terebratula*" *diodonta* Dalman 1828, as to the position of which Davidson (1869, 175–6; 1883, 151) was uncertain, is best regarded as a variety of *Camarotoechia borealis.* It is really one of the "end terms" in the range of variation exhibited by the external characters of *C. borealis*, in that it possesses but two plications within the fold, and one within the sinus. This condition is, however, accentuated by the fold usually being narrow and high and bounded by two almost vertical walls, so as to be more prominent than in few-ribbed examples of *C. borealis.* The average size of the adult appears, too, to be rather smaller than that of *C. borealis.* An examination of internal casts leaves no doubt that it is referable to *Camarotoechia*, the median septum in the dorsal valve and the cast of the crural cavity being developed in about the same degree as in *C. borealis.* It is worthy of note that *Camarotoechia borealis* var. *diodonta* has been reported on several occasions (Gardiner, *Quart. Journ. Geol. Soc.*, lxxxiii, 1927, 524; Pocock, *ibid.*, 1930, table on pl. vi; the writer has also collected it there) from the Woolhope Limestone of Woolhope, where *C. borealis* is decidedly rare. It may be that it is a local variety of *C. borealis*, but *C. borealis* var. *diodonta* certainly occurs also at Dudley.

"*Rhynchonella*" *lewisi* Davidson 1848, appears from a preliminary examination to be closely related to *C. borealis* (v. Buch); it is certainly referable to *Camarotoechia. Rhynchonella sub-borealis* Davidson 1883 (149–150, pl. x, figs. 5–6), from the Upper Llandeilo of Craighead, Girvan, however, does not seem from Davidson's description and figures to be very similar to *C. borealis* (v. Buch). "*Rhynchonella*" *bidentata* (Hisinger) 1827, seems to be quite a distinct species. The position of "*Rhynchonella*" *decemplicata* J. de C. Sowerby 1837 remains doubtful.

As to the systematic position of this form there can be no question. It agrees closely with the characters of *Camarotoechia* as described by Hall and Clarke (1894, 189–191, and pl. lvii) and Weller (1914, *Illinois State Geol. Surv., Monogr.* 1, 175–6), and a study of casts of the type species, *Camarotoechia congregata* (Conrad), from the Hamilton group of Eastern New York, and of photographs of the types, leaves no doubt that it is referable to the same genus. The main differences from the type appear to be largely ones of degree. However, the lack of distinct crenulation of the dental sockets, the position and length of the crura (these are closer together in

C. borealis, since the crural bases margin the crural cavity), and the presence of the small median plate within the crural cavity are distinctions of specific character. The latter feature appears to be absent in *C. congregata*, but it may be paralleled in *Rhynchotrema capax* (Conrad), for in this form, Hall (1860, *13th Ann. Rep. N.Y. St. Cab. of Nat. Hist.*, 67) states that in the dorsal valve " . . . in the center of the apophysary process, at the base of the crura, there is a narrow central process which is more distinct than usual ", and this similarity is further emphasized by comparing the " vertical septiform cardinal process " in Hall and Clarke's figures (1894, pl. lvi, figs. 20–22) of the same species. Externally the fold and sinus in *C. borealis* appear to be more prominent than in any of the American species of the genus figured by Hall and Clarke.

ACKNOWLEDGMENTS.

The writer is greatly indebted to Professor O. H. Schindewolf, who obtained for him a cast of the holotype of *C. borealis* in the Berlin University Museum ; to Professor Ruedemann, for supplying photographs of the types of *Camarotoechia* ; to Miss H. M. Muir-Wood for the loan of material from the British Museum, and to Mr. A. G. Brighton for access to specimens in the Sedgwick Museum. He wishes finally to express his thanks for helpful criticism and discussion to Professor O. T. Jones and Dr. O. M. B. Bulman, and for the award of a Maintenance Grant to the Department of Scientific and Industrial Research.

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ANNOUNCEMENT.

CLOUGH MEMORIAL RESEARCH FUND.

This fund was instituted in 1935 for the purpose of encouraging Geological research in Scotland and the North of England. The North of England is defined as comprising the counties of Northumberland, Cumberland, Westmorland, Durham, and Yorkshire. Under the terms of administration of the fund a sum of approximately £30 will be available annually.

Applications for grants are invited for the period 1st April, 1937, to 31st March, 1938. These applications should state :—

(1) The nature of research to be undertaken.

(2) The amount of grant desired.

(3) The specific purpose for which the grant will be used, e.g. travelling expenses, maintenance in the field, excavations of critical sections, etc.

(4) Whether any other grant-in-aid has been obtained or applied for.

Applications should be in the hands of the Secretary, Clough Memorial Research Fund Committee, Edinburgh Geological Society, Synod Hall, Castle Terrace, Edinburgh, not later than 1st February, 1937.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXIV.

No. II.—FEBRUARY, 1937.

ORIGINAL ARTICLES.

The Early Cretaceous and Miocene Peneplains of Nyasaland, and their Relation to the Rift Valley.

By F. Dixey.

I. Introduction.
II. Northern Nyasaland and the Upper Luangwa Valley.
III. Southern Nyasaland.
IV. The Lower Shire–Zambezi Area.
V. The End-Tertiary Peneplain.
VI. The Early Cretaceous Peneplain; Its Influence on Existing Land Forms.
VII. References.

I. Introduction.

In that part of Central Africa lying to the west and south of Lake Nyasa various ancient peneplains have long been known (III (9)),[1] but there has hitherto been available but little evidence whereby their relations to each other and to other more distant peneplains could be established. West and north-west of the lake, for example, there is the "4,000–foot" plateau, out of which rises the 7,000–8,000 ft. plateau of the Nyika and neighbouring highlands (see Fig. 1; also physical map in III (9)); and south of the lake, in Southern Nyasaland, the Kirk Mountains plateau (5,000 feet) overlooks the Shire Rift Valley from the west, whereas on the eastern side the eastward tilted Shire Highlands plateau is surmounted by the Zomba plateau (6,000 feet) and the Mlanje plateau (7,000 feet); the summit levels of the Mlanje Mountains, at 9,000-10,000 feet, probably indicate another ancient surface.

In the course of his recent work on the evolution of the Congo Basin, A. C. Veatch (XII) has assembled data on the great peneplain extending over the Upper Congo, Southern and Northern Rhodesia, across Northern Nyasaland, and through Western Tanganyika

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[1] The numbers in parentheses refer to References at end of paper.

Territory to Uganda and, on the basis of fossil evidence from the Belgian Congo, Southern Rhodesia, Uganda, and elsewhere, agrees essentially with other authors in regarding this peneplain as of mid-Tertiary, probably mid-Miocene, age.

In the Congo Basin a lower peneplain, the end-Tertiary peneplain, is extensively developed on the softer formations and extends as a broad valley-like feature into the areas of the harder rocks. Moreover, the present Congo Basin and adjacent areas had been base-levelled at about mid-Cretaceous time, and in Uganda remnants of an early Cretaceous peneplain, correlated with that underlying the Mesozoic sediments of the coastal belt, have been recognized as rising above the Miocene peneplain (XI).[1]

Veatch's valuable summary of available information as to the main peneplains of Central Africa has served as the starting point for the following discussion of the peneplains of Nyasaland and the inferences to be drawn from them.

II. NORTHERN NYASALAND AND THE UPPER LUANGWA VALLEY.

Although local evidence is lacking, other than that it is of post-Karroo (i.e post-Liassic) and of pre-Rift (i.e. pre-Pliocene) age, it is probably necessary to follow the views of observers in neighbouring countries and regard the main peneplain of Nyasaland and adjacent areas, ranging from 3,500 to 5,000 feet in height, as part of the great African Miocene peneplain.

An apparent difficulty arises, however, when the occurrence of Lower Cretaceous sediments in the upper Luangwa Valley and the Nyasan Rift Valley is taken into account. These sediments, of which the age is determined by the presence of fossil Dinosaurs (III (5); VI), lie along the floors of these depressions at depths of 1,500 to 2,500 feet below the level of the enclosing plateau. From this it would at first sight appear that the peneplain in the vicinity of these depressions is of late Jurassic to early Cretaceous age rather than Miocene, but the following arguments support the presumption as to the latter age.

The early Cretaceous Dinosaur Beds of the upper Luangwa Valley have been locally tilted and, probably, faulted, and hot springs occur throughout the length of the valley. But although there is thus some indication that the Luangwa Valley has been affected by Rift Valley movements, there is no evidence that its form has been appreciably modified; it is essentially a valley of erosion carved out of a faulted syncline of Karroo sediments. Moreover, subsequently to the folding and faulting of these sediments, the region was base-levelled prior to the deposition of the early Cretaceous beds.

Owing to the strong current-bedding exhibited by the Dinosaur

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[1] See also Davies, K. A., "The Age of Mt. Elgon and Events in the Tertiary History of Bugishu." *Ann. Rep. Geol. Surv. Uganda*, 1933, 69–71.

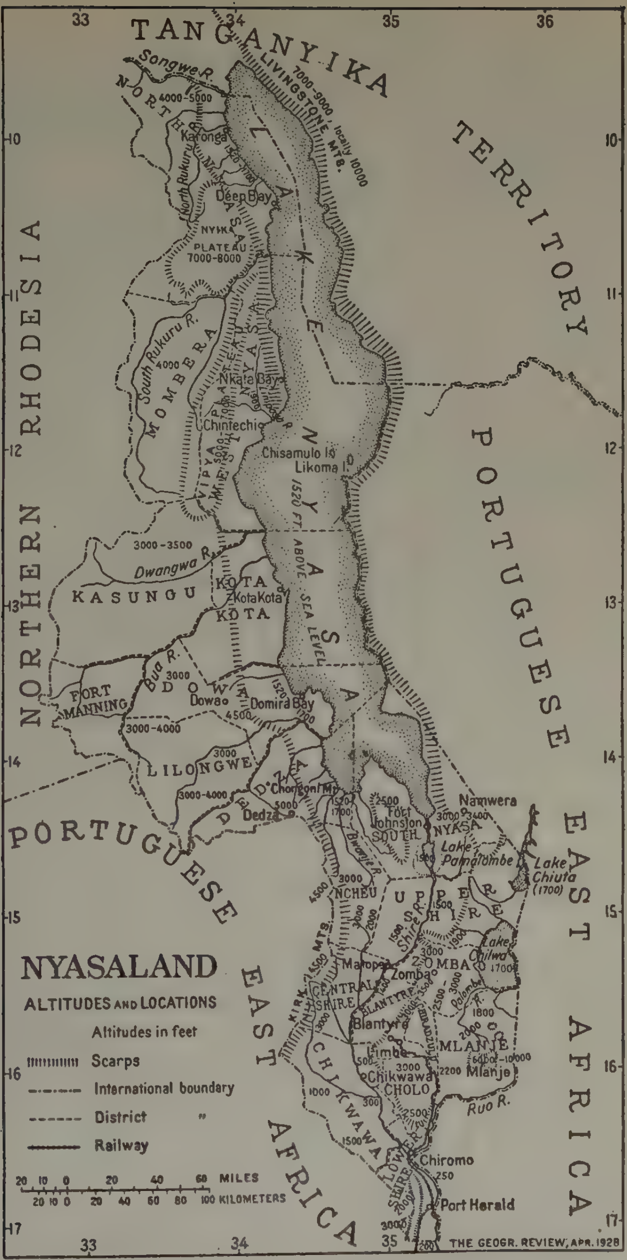

FIG. 1.—The main physiographic divisions of Nyasaland are defined by hachures and by approximate elevations.

By courtesy of the *Geographical Review*, published by the American Geographical Society of New York.

Beds and the small size of the remaining outliers, it is difficult to arrive at a satisfactory estimate of the true thickness of the beds exposed, but a thickness of upwards of 1,000 feet is probably represented, and this forms but a part of the total original thickness (III (10)). It may be assumed, therefore, that formerly the beds more or less completely filled the valley to its present depth.

I have elsewhere shown that up to the deposition of the Dinosaur Beds the Lake Nyasa depression and the Luangwa Valley developed along similar lines and were of comparable magnitude (III (10)); both were to a greater or less extent troughs of Karroo deposition separated by a ridge that persisted throughout a large part of Karroo time. In the case of the Nyasa depression the Dinosaur Beds were repeatedly tilted and faulted by the Rift Valley movements (III (2)), but there is no reason to suppose that that part of the floor on which they lie was as a whole let down to any great extent by these movements; the sinking of the floor of the rift took place mainly in post-Pliocene times slightly farther east on the site of the northern end of Lake Nyasa, the floor of which in part now stands at 700 feet below sea-level, the lake itself being over 2,000 feet deep.

Along the western shores of Lake Nyasa the Dinosaur Beds stand at about 1,600 to 2,400 feet above sea-level, and a minimum thickness of about 1,200 feet is exposed representing but a part of the full sequence; the beds must therefore originally have filled the Nyasa depression up to or near the 4,000 ft. level.

If, therefore, the upper Luangwa and the north Nyasa depressions be assumed to have been completely filled by early Cretaceous, and possibly later, sediments and subjected to a prolonged downward movement, the main plateau intersected by these depressions may be ascribed to the Miocene peneplanation, in spite of the presence of early Cretaceous sediments along their floor. The sequence of events would appear to have been essentially as follows:—

In the first place it may for the following reasons be assumed that the early Cretaceous drainage in this area lay along the course of the Rift Valley. From the present disposition of the early Cretaceous sediments the only possible alternative outlet was by way of the Ruhuhu depression. But the 4,000 ft. peneplain, shown by the accordance of summit levels, is developed on the Karroo of the Ruhuhu gap just as it is on the Mount Waller outcrop on the opposite side of Lake Nyasa; yet the early Cretaceous sediments are well developed at lake level along the foot of Mount Waller, 1,500 feet below, and thence for 80 miles northwards along the lake shore, while there is no record of their occurrence along the Manda shore or anywhere within the Ruhuhu gap (IX). Hence, in view of the well-developed form of the Nyasa depression at this time, and of the occurrence of similar deposits in the Shire Valley, it is more than probable that the early Cretaceous drainage followed a depression on the line of the Rift Valley. By a similar argument another line of drainage lay along the Luangwa Valley and the Lower Zambezi reinforced in this case by the existence of an easily-eroded trough of Karroo sediments along the whole route.

Accordingly, from the accumulation of a great thickness of coarse fluviatile sediments in the great valley, combined with the transgression of the Cretaceous sea in Tanganyika Territory, Mozambique, and on the Lower Zambezi (III (7), p. 243), a prolonged movement of depression may be taken to have occurred in this region, whereby the ancient valley became largely or entirely filled. Then followed the peneplanation culminating in about the middle Miocene, succeeded in turn by the late Miocene uplift, whereby the sediments were largely removed from the north Nyasa valley and the Lower Shire, and, as far as present knowledge goes, entirely eroded from the intermediate section of the old valley.

For these reasons the "4,000-foot" peneplain of Northern Nyasaland and the Upper Luangwa Valley will be assumed to be of Miocene age, but it may be remarked that here, as in other areas, it has suffered a considerable amount of warping, being locally 5,000 feet or more above sea-level, and elsewhere less than 4,000 feet. This warping in the main preceded, or possibly in part accompanied, the formation of the Rift Valley.

With this starting point the 7,000–8,000 ft. plateau of Northern Nyasaland, comprising the Nyika plateau and neighbouring similar uplands (see Fig. 1), as well as the Livingstone Mountains plateau (8,000–9,000 feet) on the opposite side of Lake Nyasa, may safely be ascribed to the Cretaceous peneplanation, since it also cuts across the main Karroo boundary faults. In general, as around the flanks of the Nyika plateau, the older peneplain is separated from the younger peneplain by steep slopes, and the relative ages of the two surfaces are apparent from physiographical considerations.

Although perfect base-levelling was attained even in the early part of the Cretaceous (XII, pp. 30 and 144) the end-stage of the great African Cretaceous peneplain is ascribed by Veatch to about the mid-Cretaceous (XII, p. 162), apparently mainly on account of the evidence from the Angola coastal plain, where sediments of Aptian, or uppermost Lower Cretaceous, age rest upon a surface almost perfectly base-levelled (XII, p. 29). In the area now considered, however, the uplift and erosion of the peneplain must have commenced at an earlier date, such as the beginning of the Cretaceous, or even possibly the end of the Jurassic, since the Dinosaur Beds, laid down across the Karroo boundary faults and in great valleys eroded 2,000 feet or more into the Karroo sediments, are themselves of early Cretaceous age. This would appear to be borne out by the stage of development of the peneplain as seen on the Nyika plateau, for, when due allowance is made for the effects of erosion, although the greater part of the surface lies between 6,000 and 7,000 feet, it rises near the eastern ridge to about 8,300 feet so as to form a ridge which was probably a residual feature on the old surface. Moreover, the peneplain only partially graded the Mlanje massif (p. 55). Elsewhere, however, the base-levelling was essentially complete.

It will accordingly be convenient to refer to this peneplain as the early Cretaceous peneplain, although it is probable that in some areas movement began even before the close of the Jurassic.

To the south-east the Nyika plateau is divided from the northern end of the Vipya plateau by the broad lower Henga Valley, opened out on Karroo sediments during the Miocene peneplanation. The upper part of the Vipya is upwards of 6,000 feet in height, and it is evidently a continuation of the old surface represented on the Nyika, which it carries another 100 miles farther south along the eastern edge of the plateau overlooking the Nyasan Rift. Still farther south there is the small plateau remnant forming the summit of Dedza Mountain, an isolated and dissected flat-topped ridge rising steeply about 2,000 feet above the Dedza Miocene peneplain, here standing at about 5,000 feet. A few miles to the north-west the Chongoni Highlands also bear evidence of an ancient elevated peneplain.

III. Southern Nyasaland.

Continuing still farther south along the main pre-Rift plateau of Nyasaland, still presumably representing the Miocene peneplain, there is no further evidence of an older surface until the Shire Highlands are reached, on the opposite side of the Rift Valley. Here the Miocene surface is clearly tilted away from the edge of the Shire Rift Valley towards the east; near its western edge it bears the elevated Zomba plateau, and Chiradzulu ridge, and from its eastern margin rise the Mlanje Mountains; these elevated and isolated uplands bear the same physiographical relations to the Shire Highlands plateau as the Nyika and associated uplands do to the main plateau of Northern Nyasaland. The same age relations may therefore fairly be assumed, since the two peneplains represented are both post-Karroo and pre-Rift. The post-Karroo age is known from the relation of the Karroo sediments to the main peneplain of Southern Nyasaland, and from the late Karroo age of the syenite intrusions making up the Mlanje and Zomba masses.

Zomba plateau is a rolling grassy surface lying between 6,000 and 7,000 feet in height; it is about 12 miles long and 5 miles wide, and it is bounded on all sides by steep slopes leading down to the younger peneplain; along the western edge it directly overlooks the Rift Valley. Chiradzulu is a steep-sided ridge, of which the upper surface shows evidence of former peneplanation. Mlanje is a mass measuring about 15 miles across, with a maximum height of about 10,000 feet. It bears ample evidence of dissection down to a level of 6,000 to 7,000 feet, and around its flanks are several well-defined little plateaux of this altitude with rolling grassy surfaces, each several square miles in extent. These are similar to, and clearly correspond with, Zomba plateau and the crest of Chiradzulu.

The rocky summit levels of Mlanje lie between 9,000 to 10,000 feet, and appear to represent an ancient surface of some kind, possibly the original upper limit of the syenite intrusion, since contact-altered sediments, probably Karroo, lie on the flanks at about 7,000 feet.

The Shire Highlands plateau may therefore be referred to the Miocene peneplain and the Zomba, Mlanje, and Chiradzulu plateaux to the early Cretaceous. The evidence of certain minor platforms with accordant valleys disposed around the flanks of Mlanje, as at Likubula, as well as the cottage "plateau" standing about 1,000 feet below the main Zomba plateau, shows that the reduction from the older to the younger peneplain took place in two or more stages. These platforms possibly correspond to the secondary Cretaceous peneplain of the Lower Shire–Zambezi area (see p. 56).

What appears to be another remnant of the early Cretaceous peneplain occurs on the Namuli mountains,[1] in Portuguese East Africa, about 100 miles north-east of Mlanje, and the mountains themselves rise out of what is apparently a continuation of the Shire Highlands Miocene peneplain.

Near the Shire–Zambezi confluence Marambala ridge rises abruptly out of a low-lying plain of pre-Karroo rocks, overlain to the south and east by Cretaceous and later sediments. The upper surface, standing 4,000 feet above the surrounding lowland, is clearly a fragment of an ancient peneplain, and analogy suggests that here again exist representatives of the Cretaceous and Miocene peneplains. The ridge lies between the Shire Rift Valley and the Urema sunkland, and on this account has hitherto been regarded as probably forming part of the Rift Valley structure of this region (x (3), p. 31).

Reference may here be made to the fact that the scarps bounding the Mlanje and Zomba plateaux have hitherto been regarded as Rift Valley faults (I; III (2)), and this is not surprising in view of their close association with Rift Valley structures. Subsequent work has, however, thrown doubt on this interpretation. For example, the scarps themselves follow closely the limits of the syenite intrusions that build up the Mlanje and Zomba masses, just as the Nyika scarps follow the limits of the indurated sediments enclosing the Nyika granite; also, on two sides of Mlanje cognate dykes of sölvsbergite and other rocks can be traced for miles across the surrounding lowland plain and up the flanks of the main syenite intrusion without indication of any such disturbance as would be expected from faults with the requisite downthrow of about 4,000 feet. Moreover, of the numerous other larger hills and mountain masses rising above the main plateau of Nyasaland, almost all, including Chiradzulu, Dedza, and Chongoni, consist of the syenitic and, rarely, other plutonic intrusions in the prevailing gneisses, and there is no reason to regard them as due to anything more than ordinary processes of erosion. The few upstanding masses not falling within this category of intrusions consist of limestones, quartzites, and other resistant bands in the gneisses. Even the minor intrusions surrounding the late-Karroo syenites of Mlanje, Zomba, and elsewhere almost invariably give rise to little hills and ridges.

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[1] J. Vincent, "The Namuli Mountains, Portuguese East Africa," *Geogr. Journ.*, 81, 1933, 314–327. See also ensuing discussion on East African peneplains by J. Parkinson, p. 330; E. J. Wayland, 83, 1933, 95; and Bailey Willis, pp. 383–4.

The facts as at present known are more readily explained by the present suggestion that the numerous elevated smaller plateaux extending throughout the length of Nyasaland from the Nyika to Mlanje are due merely to the survival of remnants of an ancient peneplain, post-Karroo and presumably early Cretaceous, on isolated masses of resistant rocks hard enough to withstand the Miocene peneplanation. Across the ancient pattern the local Rift Valley system subsequently developed.[1]

Nevertheless, it is perhaps no mere coincidence that the plateaux of the Livingstone Mountains, Nyika, Vipya, Dedza Mountain, Zomba, Chiradzulu, Port Herald Hills, and Marambala, all directly overlook and are in general aligned parallel with the Rift Valley, and that Mlanje overlooks the Lake Chilwa depression, which was probably formed as a result of the Rift Valley movements; that there are no other masses of comparable height on either side of the Rift Valley within hundreds of miles, even when allowance is made for the local tilting of the Miocene peneplain away from the Rift Valley; that in the north the Nyika and Vipya extend along a Karroo ridge, whereas the adjacent part of the Rift Valley occupies a Karroo basin of deposition; that in the south the Rift zone traverses a cluster of late-Karroo plutonic intrusions and volcanic necks; and that in the north and the south the Rift Valley coincides with troughs of early Cretaceous sedimentation. These features all point to the existence in this region of ancient structural lines that have repeatedly influenced the course of later events.

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[1] Since this paper was written Mr. C. Gillman has called my attention to somewhat similar observations he has made in Usandawi in North-Eastern Tanganyika Territory (*Tanganyika Territory Geol. Surv., Ann. Rep.*, 1934, 31–2). Here a broad belt of markedly hilly, and in parts still mountainous, country, known as the Chenene Range and Usandawi Hills, forms the bold northern boundary wall of the slightly warped or tilted peneplain basins of Central Ugogo. The view of earlier investigators was that the range was bounded both on the north and the south by fault-line scarps, whereas Mr. Gillman, on physiographical grounds, regards the mountains as forming a great granitic remnant-range, 160 kilometres in length, accompanied on either side by extensive peneplanation; the range and the peneplain are in places intersected by N.E.–S.W. fracture-lines of the Central Shatter Belt. The alternative view is in complete accord with that now presented for certain of the old "fault-line scarps" of Nyasaland. Furthermore, the Chene-Usandawi range is 15 to 20 kilometres in width, and it rises above the adjoining plains 400 to 500 metres in the south-east and 200 to 300 metres in the north-west, while individual old remnant hills stand out considerably higher from a generally fairly even ridge height. The relation between the two peneplains thus indicated is analogous with that between the two peneplains of Nyasaland now ascribed to the early Cretaceous and the Miocene.

IV. The Lower Shire-Zambezi Area.

It is difficult to do more than indicate the broad lines of the course of peneplanation along the Lower Shire and the Lower Zambezi, owing to the somewhat complex geological history of the area.

The Shire Rift Valley is a well-defined feature as far south as the latitude of Blantyre (Fig. 1). Southwards of this the eastern wall continues to within a few miles of Chiromo as a bold scarp, which may be called the Cholo scarp (Fig. 2) about 3,000 feet in height, which forms the western limit of the Shire Highlands (See also Physical Map in III (9).) Meanwhile, the western wall gradually loses height and, with the floor of the rift, finally merges into an extensive low-lying area of Karroo, Cretaceous, and later sediments bounded on the east by the high eastern wall already referred to.

If, for the reasons already given, the Shire Highlands plateau be accepted as representing the Miocene peneplain, we meet again, as in Northern Nyasaland and the Luangwa Valley, the difficulty of an elevated peneplain of this age overlooking a lowland of early Cretaceous sediments; furthermore, these sediments extend across the floor of the Shire Rift Valley and the lowland area co-extensive with it.

Throughout the greater part of Karroo, Cretaceous, Tertiary, and later times the Lower Shire–Zambezi area and the adjacent seaward area have formed a low-lying zone of sedimentation. Furthermore, the presence of early Cretaceous sediments about, or even within, the Lower Shire Rift, as well as in the Nyasan Rift and the Luangwa Valley, together with the occurrence down the Shire Valley of pebbly deposits recalling those seen in the vicinity of the early Cretaceous outcrops, suggests that the Shire Rift Valley is also a feature dating in part from early Cretaceous times, although modified and enlarged by the late Tertiary Rift movements.

The early Cretaceous sediments already referred to, occurring mainly along the Lower Zambezi but represented also in the Lower Shire, pass eastwards beneath the upper Cretaceous and Tertiary marine sediments of the Inhaminga plateau (VIII; X), standing at about 1,100 feet above sea-level, and during upper Cretaceous and a large part of Tertiary and later times the seaward area at least must accordingly have been undergoing slow subsidence, to a probable depth of several thousand feet by the end of the Tertiary. The age of the early Cretaceous sediments is indicated on stratigraphical grounds and by analogy with the early Cretaceous Dinosaur Beds of Northern Nyasaland (III (7); VIII; X).

The disposition of the early Cretaceous sediments affords evidence as to the existence of the early Cretaceous peneplain in this area. Along the northern bank of the Zambezi the basal sandstones extend for about 100 miles across a fairly even surface of erosion comprising the whole local range of Karroo sediments from Ecca to Stormberg, as well as the Stormberg lavas; moreover, near Sinjal they stretch across the main Karroo boundary fault on to the pre-Karroo crystalline rocks and back again on to Karroo basalts. This surface of erosion nonetheless represents but an imperfect peneplain, and it may for convenience be referred to as the secondary early Cretaceous peneplain, as distinguished from the main early Cretaceous peneplain in the production of which much the greater part of the vast erosion indicated was effected. In the course of the main peneplanation all formations, including the harder igneous and metamorphic rocks, were levelled off, but the secondary peneplanation, relatively of short duration, was effective only on the softer sediments, and the harder outcrops were left in relief. Accordingly the larger and more resistant Stormberg and associated lavas and intrusives and some of the harder metamorphic rocks still retain base-levelled upper surfaces, while the softer rocks surrounding them have been evenly levelled off at about 1,300 feet below. For example, Salambidwe Hill, 6 or more miles across, an intrusion of syenite and nepheline-syenite, and Muambe Hill, about 6 miles in diameter, a carbonate-felspar rock vent, both intrusive into Karroo sediments, and the ridge of Stormberg rhyolites, interbedded with the basalts, all show this structure and the peneplain surrounding them passes beneath the basal Cretaceous sediments. Also, in and west of the Port Herald Hills, the isolated hills of quartzite and of intrusive nepheline-syenite, such as Nyapanda, Domwe, Mbungwa, and Malawe, are probably of similar origin.

It is evident that in the interval between the two peneplanations considerable movement must have occurred, and it is probable that at this time some local vertical displacement between the Karroo-Cretaceous lowland and the inland plateau took place, leading to the formation of a depression on the site of the Lower Shire Rift Valley, in which the succeeding early Cretaceous sediments were laid down. Furthermore, in view of the unusual coarseness of these sediments throughout, the local unconformities, and the accompanying volcanic outburst, it is clear that the movements were then accentuated, giving rise to a strong relief in the adjacent inland area, that following subsidence during the Cretaceous sedimentation, was again to a large extent levelled off during the Miocene peneplanation.

Attention may here be called to the close analogy that exists between the Cretaceous and Tertiary record of the Angola coastal plain, as described by Veatch (XII, p. 30) and that of the Lower Shire-Zambezi area. The record of each area indicates that there existed in Central Africa an extremely well-graded peneplain at the beginning of the Cretaceous; that following the uplift of this peneplain in early Cretaceous times its relatively down-warped or down-faulted portion was preserved beneath sediments, and correspondingly its up-warped portion inland was almost completely destroyed by erosion; and that this erosion continued on the up-warped portion throughout the Cretaceous, the Eocene, and the

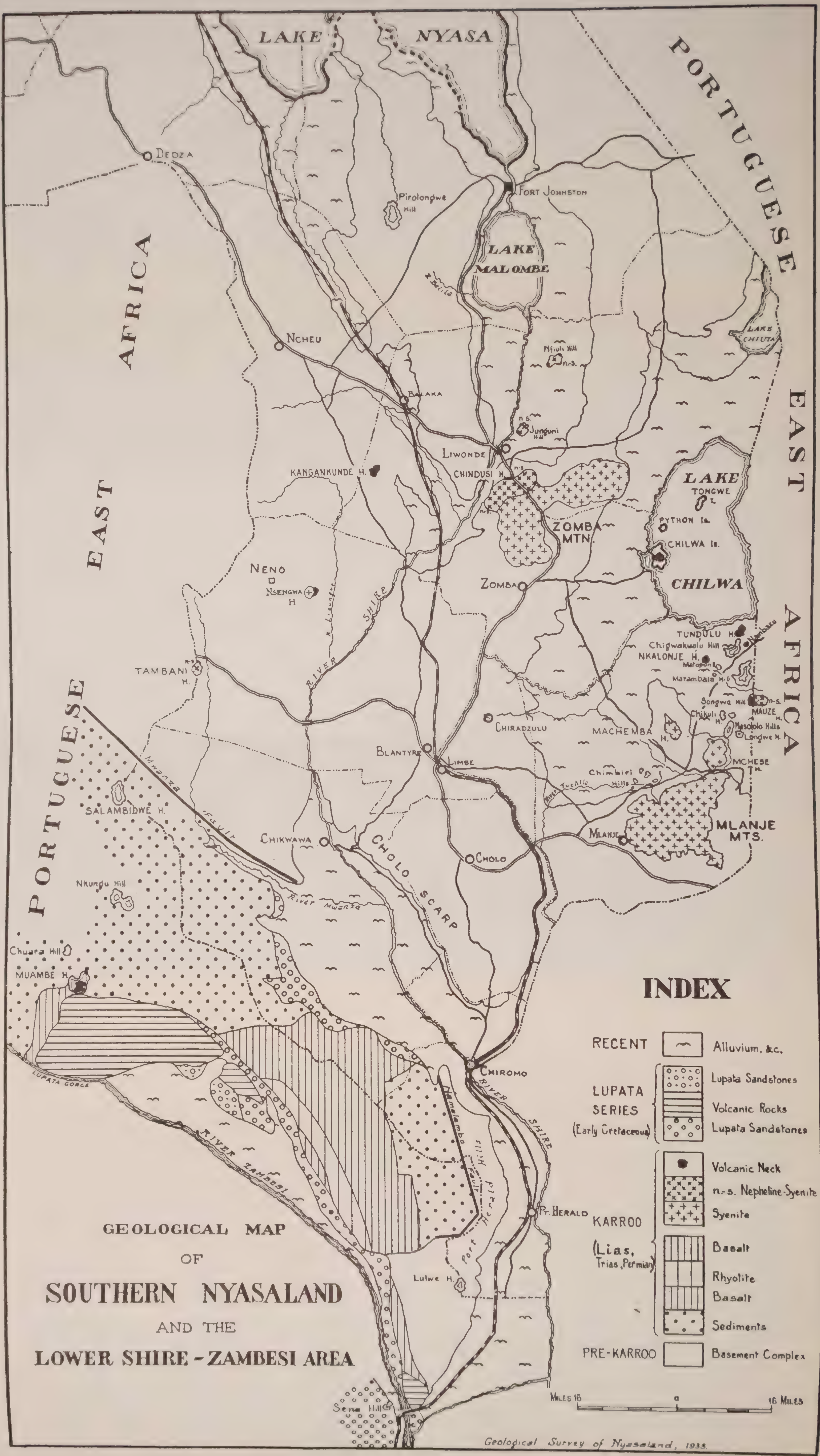

Fig. 2.—Geological Map of Southern Nyasaland.

[To face p. 30.

Oligocene, and part of the Miocene, with the production ultimately of the Miocene peneplain, while at the same time sediments were accumulating in the down-warped seaward areas.

It would thus appear that in the early Cretaceous as also in the mid-Tertiary and the late Tertiary (p. 62), the central part of the African continent was uplifted, while the coastal regions on both the east and the west were up-tilted towards the interior.

Events in the region of Northern Nyasaland in the meantime followed a course similar to that of the Lower Shire–Zambezi area. After the main early-Cretaceous peneplanation a great uplift took place, accompanied by rapid erosion of the Karroo in the North Nyasa and Upper Luangwa troughs; then on the softer Karroo sediments the secondary peneplain was developed over the broad floors of the troughs, but the peneplanation was not complete, since the structure of the Karroo was still etched in strong relief when the early Cretaceous sedimentation commenced. Subsidence then followed, permitting the accumulation of fluviatile sediments in the valleys and the encroachment of the Cretaceous sea, and after that came the Miocene peneplanation. The North Nyasa pre-Cretaceous floor now stands about 1,000 feet below that of the Upper Luangwa, and later movements have carried part of the Rift still lower.

The uplift between the main and the secondary peneplanations was much greater in the northern, i.e. the inland, area than in the south, where for purposes of the present discussion the two peneplanations may usually be regarded as one.

Examination of the map of the Lower Shire–Zambezi area (Fig. 2) shows that the secondary peneplain, together with the overlying sediments, was folded into the form of a gentle anticline striking north-west and south-east. Furthermore, the Anglo-Portuguese border, following the watershed, runs along the crest of the anticline, with respect to which the outcrop of the sediments and the courses of the Lower Shire and the Lower Zambezi all run symmetrically. For the most part the peneplain is still well preserved over the broad crest of the anticline, from which the sediments have but lately been denuded. It will be observed also that the Port Herald Hills extend right across the anticline; they are due to an ancient surface of erosion that at the highest part, on the strike of the anticline, forms a dissected plateau, whereas on the south-west it assumes the dip of the early Cretaceous sediments along the Zambezi, and finally passes beneath them, and on the north and north-east it passes down beneath the alluvium along a line on the strike of the north-east limb of the anticline. The structure is indicated also by the form of the crystalline rocks along the main eastern Karroo boundary fault; at Sinjal the pre-Karroo side of the fault emerges from beneath the south-west limb of the anticline, rises to a broad maximum, where it crosses the crest of the anticline and falls gradually on the other side to pass beneath the alluvium bounding the north-east limb. Accordingly, the Port Herald Hills may be regarded as a dissected remnant of the early Cretaceous peneplain folded in anticlinal fashion with the formerly overlying Cretaceous sediments. It represents in the main the secondary peneplain, whereas the main peneplain is apparently represented by the crests of the isolated hills of harder intrusions rising above the general level. It may be noted, too, that the isolated Nachipere outcrop of Karroo coal shales rests on the plateau near the crest of the anticline, and also that this outcrop is on the site of a ridge existing in Karroo times, since elsewhere in this region a thickness of over 4,000 feet of Lower Sandstones intervenes between the coal shales and the pre-Karroo basement rocks (III (8)).

Similar arguments show that the western part of the Shire Rift Valley west and north-west of Chikwawa is also a tilted remnant of the early Cretaceous peneplain. For the main Karroo boundary fault running along the north-east bank of the Mwanza River, and with it the pre-Karroo crystalline rocks along the upthrow side of the fault, gradually emerge from beneath the early Cretaceous and recent sediments and rise northwards for about 45 miles until they approach the ill-defined southern limit of the Kirk Mountains plateau, already ascribed to the Miocene ; at the same time this early Cretaceous surface slopes north-eastwards towards the Shire River, since it also is affected by the Lower Shire–Zambezi anticline.

Accordingly, what is the relation of the Lower Shire–Zambezi area, with its early Cretaceous peneplain, to the Rift Valley, and to the Shire Highlands Miocene peneplain, which directly overlooks it from a height of about 3,000 feet, and why did the early Cretaceous peneplain of this lowland escape the Miocene peneplanation ? The available evidence points to the following sequence of events. After the break-up of the early Cretaceous peneplain the region was in a state of great instability throughout the lower Cretaceous, as shown by the coarseness of the sediments then laid down, the local unconformities, and the volcanic activity, and it is probable that during the movements of this time the inland plateau became uplifted relatively to the sedimentary area and that a local depression, subsequently occupied by early Cretaceous beds, developed on the site of the Shire Rift Valley. The sedimentary area remained at a low level or more probably subsided below sea-level for a long period, since the upper Cretaceous and lower and upper Tertiary marine sediments of the Sheringoma plateau, south of the Lower Zambezi, extend to within 25 miles of the Shire–Zambezi confluence and overlie the early Cretaceous of the Lower Shire–Zambezi area.

Following the subsidence of middle and upper Cretaceous times already referred to, the upland areas resulting from the upheavals of the early Cretaceous were again base-levelled in the early Tertiary. Then ensued the Miocene uplift of 3,000 to 4,000 feet to form the Shire Highlands, Kirk Mountains, and other parts of the African plateau. Consideration of the relation of the Karroo of the Lower Shire, Lower and Middle Zambezi, to this plateau shows that these sedimentary areas, peneplaned with the basement rocks, took part in this uplift but have since been reduced to their present level by erosion.

What, then, is the origin of the Cholo scarp of the Shire Highlands? The following factors have entered into its development :—

(*a*) Early Cretaceous movements; the distribution of the early Cretaceous sediments, and analogy with the North Nyasan Rift indicate that these were important.

(*b*) Miocene movements; the relation to the course of the Rift Valley and the tilting of the Shire Highlands away from the Rift indicate that the Miocene faulting and tilting played a part.

(*c*) Post-Miocene erosion; the manner in which the scarp overlooks the lowland of Karroo and Cretaceous indicates, for the reason given above, that the scarp owes its present configuration largely to the removal of sediments; this is supported by the proximity of the scarp to an important Karroo boundary fault, and by the known total thickness of the Cretaceous and early Tertiary sediments of this region. The local base of the Cretaceous rests on the Karroo beneath the alluvium probably near the foot of the scarp; the total local thickness of the early Cretaceous sediments was at least 2,500 feet and probably much more [1] (III (6); VIII (2)); they dip eastwards beneath upper Cretaceous and Lower Tertiary, of which the total thickness is about 750 feet (VIII (2)), and if these extended inland as far as the scarp the total thickness of the Cretaceous and early Tertiary would have been upwards of 3,250 feet, more than sufficient to bring the sediments up to the level of the Miocene peneplain. Sedimentation in the Sheringoma region recommenced in the upper Tertiary (VIII (2)), indicating an eastward seaward tilt as the inland regions rose.

(*d*) Post-Tertiary faulting, as in the Urema sunkland; the broad and probably deep strip of alluvium along the foot of the scarp and thence seawards may conceal late rift- or hinge-faulting.

It is not yet possible to evaluate the relative importance of these different factors, but it is perhaps probable that (*a*) and (*c*) have contributed most towards the formation of the scarp, which is therefore no simple Rift-Valley feature but one of great antiquity.

The late Miocene uplift accompanied or followed, by block faulting, with tilting of the Shire Highlands block towards the east, accordingly involved the scouring of the Lower Shire depression, with removal of early Cretaceous and possibly later sediments therefrom, and also relative down-faulting and perhaps enlarging of this depression into its present form of the Shire Rift Valley. On this basis in the region where the western wall of the Shire Rift Valley gradually diminishes in height and dies out, while the eastern wall continues boldly and without interruption, the former is due to the emergence of an older structure, i.e. a tilted fragment of the early Cretaceous peneplain, while the latter would appear to be due to repeated movement along the one line.

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[1] Cf. over 4,000 feet for the early Cretaceous Uitenhage Series of Cape Province (see p. 65).

This section of the Shire Rift Valley is therefore of complex origin, and in the association of events in the Karroo, the early Cretaceous, and the Tertiary that have contributed to its present form it is closely analogous with the Northern Nyasan Rift Valley, and, to a less extent, with the Upper Luangwa Valley.

Accordingly, both the northern and southern ends of the Nyasaland section of the Great Rift Valley are intimately associated with structures originating in the early Cretaceous, or even in the Karroo, and the inference may therefore be drawn that the development of the Rift Valley in these areas has followed lines of weakness that have been effective over a long period. Between these two areas the Rift Valley is a continuous feature, and it is therefore not unlikely that a similar statement would hold for the intermediate section, although no sediments are known by which its history can be traced.

V. The End-Tertiary Peneplain.

In the region considered the end-Tertiary peneplain, known in other parts of Africa (IV; XII), has not yet been definitely recognized, but there are various surfaces of erosion that may perhaps be related to it.

The late Tertiary sediments of Sheringoma plateau, now standing at about 1,100 feet, have been peneplained, as shown, for example by the strong relief of the resistant limburgite intrusives cutting these beds (II; VIII). A late Tertiary peneplain, uptilted towards the interior, has long been recognized elsewhere around the coastal belt of southern Africa (IV; VII).

The upper surface of the early Cretaceous Dinosaur Beds of the northern end of Lake Nyasa represents a dissected and tilted surface of erosion lying at about 1,650 to 2,400 feet; it is overlain by the Chiwondo Beds yielding mammalian remains ascribed to the end-Tertiary or early Pleistocene, and it therefore probably represents a valley-form development of the end-Tertiary peneplain. The corresponding surface in the Upper Luangwa Valley is probably of similar age and origin, although no younger beds have yet been found on it; moreover, it stands at about 2,500 feet, and this greater elevation as compared with that of the Nyasan beds is probably due to the effect of subsequent rift movements.

VI. The Early Cretaceous Peneplain; Its Influence on Existing Land Forms.

From consideration of the remnants of the early Cretaceous peneplain in relation to the surrounding Miocene peneplain it is possible to reconstruct the condition of the older peneplain in Miocene times, and from this it follows that much of the existing topography in the neighbourhood of the Nyasan and Shire rifts is due as much to the incompleteness of the early Tertiary peneplanation as it is to post-Miocene movements. Moreover, certain of the higher scarps directly overlooking the rift valley, such as the eastern Nyika and the western Zomba scarps, are due as much to this relict topography as to the rift faulting.

In Northern Nyasaland the eastern edge of the Nyika plateau stood nearly 4,000 feet above the new peneplain, whereas the western edge stood at about 3,000 feet; much of the Vipya stood at 2,000 feet or less. The highland ridges to the north-west of the Nyika rose to heights of 2,500 to 3,500 feet, and a large part of the Livingstone Mountains stood at about 3,000 feet.

But in the area opposite the Livingstone Mountains, between the Nyika plateau and the Songwe River, the old surface represented by the high ridges of the Misuku area dipped down into the new peneplain in the direction of these mountains, and the post-Miocene uplift and erosion has enabled us to follow this old surface down to modern lake level and thence to the foot of the Livingstone scarp. That this is in the main a Cretaceous and not a Miocene feature is clear from the facts that upon it lie the early Cretaceous Dinosaur Beds; that it is in this region that these beds extend farthest west, namely about 30 miles west of Lake Nyasa; and that here, in contrast with the other margins, there is no appreciable scarp to the Nyasan trough, but only a gentle slope that continues up to the Miocene peneplain, and thence, in a deeply dissected form, up to the early Cretaceous peneplain.

Farther south the Chongoni and Dedza plateaux stand about 2,000 feet above the younger peneplain, while the Mlanje marginal plateaux stand 4,000 to 5,000 feet above it, Zomba plateau 3,000 feet, and Chiradzula plateau about 2,500 feet.

In the Lower Shire–Zambesi area the early Cretaceous peneplain was submerged beneath Cretaceous sediments well below the level of the Miocene peneplain; it is now tilted towards the foot of the Cholo scarp of the Shire Highlands, and stands about 3,000 feet below the Miocene peneplain preserved on these highlands, and about 6,000 feet below the remnants of the early Cretaceous plateau rising out of them.

As in the comparable case of the North Nyasa Cretaceous surface tilted down towards the foot of the Livingstone Mountains, aligned in a direction similar to that of the Cholo scarp, the age of the Lower Shire surface is known from the age of the sediments resting upon it. Moreover, for the reasons given in an earlier section, both these surfaces must have assumed their present attitude, in large part at least, prior to the Miocene peneplanation.

It is difficult to account for these relations except on the assumption that extensive faulting took place along these two scarps in Cretaceous times; the sedimentation would appear to have been due in the first place to the formation of depressions resulting from the faulting, but in view of the magnitude of the movement, probably of the order of 6,000 feet, it is possible that further faulting took place after or even during sedimentation, as suggested by Rastall and du Toit (IV, p. 439; XIII, p. 146) for the great Worcester and Egosa faults of similar age in South Africa.

It would appear, therefore, that prior to the Miocene peneplanation the early Cretaceous peneplain of this region was subject to uplift, fracture, block faulting, and erosion, with local sedimentation, comparable with that subsequenty imposed upon the Miocene peneplain in the same area. Possibly the gentle anticline affecting the early Cretaceous sediments of the Lower Shire also dates from this time.

This conception as to disruption and erosion of an early Cretaceous peneplain and its influence on subsequent events possibly introduces a new feature into the geology of the inland regions of this part of Africa, since hitherto there has been but little evidence whereby the gap between the early post-Karroo faulting and the Miocene peneplanation could be filled in. It will therefore be of interest to consider to what extent support for this view is available from other areas.

Reference may here be made to the great scarp extending along the western side of the Urema trough south of the Lower Zambezi in Portuguese East Africa; this trough, faulted on the east against Upper Cretaceous, Eocene, and later sediments, is considered to represent the southern continuation of the great African rift zone (X (2), p. 278). This western scarp consists of gneiss; it rises suddenly from 200 to 1,000 feet above sea-level and extends for 200 miles in a north-and-south direction. It forms the western limit of Karroo sediments and lavas, and of Cretaceous and probably also Tertiary sediments, and it has been dated at various times ranging from the Lower Cretaceous to the post-Miocene (XIII, p. 21). Although no actual fault-sections have been noted along this scarp, Teale, after careful review of the evidence (X (2), p. 78), considers it "difficult to account for the physiographical features by structural factors alone. The scarp may either be regarded as of recent development or of Cretaceous or Karroo age, and due then in the two latter cases to the stripping off of the softer littoral sediments by recent erosion. In any case it seems most probable that a certain amount of tectonic action must be attributed to its formation, and the view that appears to harmonize most with requirements is that there has been recent dislocation along an old tectonic line".

The problems presented by this scarp are therefore comparable with those presented by the Cholo scarp and the Livingstone scarp, and the conception of large-scale Cretaceous faulting, combined with faulting in later, and possibly earlier, times would appear to offer a satisfactory explanation in all three cases. Possibly a comparable succession of movements took place farther north along the coast, in North-Eastern Tanganyika territory, west and south-west of Tanga, where the latest available geological map (X (4)) shows a fault or series of faults, 100 miles in length, separating the Basement Complex on the west from sediments on the east; at either end the fault brings the Karroo against the pre-Karroo, whereas elsewhere along its length it separates first the Jurassic and then the Cretaceous from the pre-Karroo.

In Northern Madagascar there was continuous sedimentation from the uppermost Karroo into the Jurassic and the Cretaceous. In Tanganyika Territory the close of Karroo sedimentation was marked by an extensive Jurassic marine transgression west of the present coastline. Along the Lower Zambesi Jurassic sediments have not been recognized beneath the early Cretaceous, and around the coast of South Africa there is a wide gap between the Karroo and the Lower Cretaceous.

Inland the middle and later Jurassic were marked by faulting, peneplanation, uplift, and erosion. The main boundary faults of the Karroo as far north as the Luangwa Valley and the coastal region of Portuguese East Africa are attributed by du Toit to the mid-Cretaceous (IV, p. 439), and those of Tanganyika Territory would appear to be ascribed to the late Cretaceous (X (4), p. 25). But observations from the Luangwa Valley, Northern Nyasaland, and the Lower Zambezi all show conclusively that the corresponding faults of these areas are of early post-Karroo, i.e. of early post-Liassic age; for the faults are overlain by early Cretaceous sediments, and prior to the deposition of these beds and subsequent to the faulting the region had been subject to a vast peneplanation, uplift of some thousands of feet, and deep erosion. The faults would therefore appear to date from some time near the mid-Jurassic.

But the suggestion now put forward as to extensive uplift, fracturing, and erosion in the early part of the Cretaceous in the Nyasa region receives support, particularly as to southern Nyasaland, from the comparable events of this period in South Africa (IV; XIII). An ancient peneplain standing 4,000 feet above sea-level is recognized in the Vaal and Orange catchments, and upper Cretaceous dinosaurs are recorded from a valley in what may be the western part of this surface in South-West Africa (XIII, p. 21). Yet within the Folded Belt of the Cape Province the early Cretaceous (Neocomian) sediments were laid down, under arid or semi-arid conditions, upon a surface as deeply dissected and rugged as that visible to-day. The great synclinal valleys of the Cape Ranges were completely filled by these sediments, which attained a thickness of more than 4,000 feet, and were at first terrestrial, then estuarine, and finally marine as the continent sank and the Cretaceous ocean invaded the valleys from the east.

But towards the end of the Lower Cretaceous (Aptian) faulting took place within the Folded Belt causing downthrows of some thousands of feet, and giving rise to new longitudinal troughs situated on the ancient buried synclines. This faulting was completed before the Upper Albian. It is considered that uplifting was associated with the down-faulting, whereby the troughs were filled with coarse sediments derived from the upthrow side, as notably in the case of the great Worcester fault, east of Capetown, which has a downthrow of 2 miles, and the Egosa fault of Pondoland, in eastern Cape Province. Local folding also took place as a renewal of movement along the Cape Foldings. Moreover, the Natal foldings, as exemplified in the great Lebombo anticline, on the western borders of Portuguese East Africa, began in the Jurassic and continued into the Lower Cretaceous, but ceased before the Upper Cretaceous. By the end of the Jurassic mountain-building in South Africa was apparently reaching its climax and the valleys were becoming choked with waste from the slowly rising arches; and with the deepening of the main troughs, under the renewal of folding and subsidence of the land, the sea entered the valleys from the east. Finally, extensive faulting culminating at about the mid-Cretaceous took place around the coasts of the southern part of the continent (IV, p. 438).

A close analogy can therefore be drawn between parts of Southern Africa and the Lower Shire–Zambezi area, as well as the Nyasan Rift and the Luangwa Valley, in respect of the sequence of events in the late Jurassic and the early Cretaceous, particularly as to the infilling of deep valleys with thousands of feet of coarse detritus under arid or semi-arid conditions. Moreover, the uplift and postulated faulting at the beginning of and during the Lower Cretaceous along the Cholo and Livingstone scarps, and west of the Urema trough, have their counterparts in movements long known to have occurred in South Africa.

In the light of the preceding discussion it is therefore possible to indicate the probable course of development of the Rift Valley in the neighbourhood of the Nyasa–Shire Rift. From this it seems that the hitherto accepted explanation as to origin by the relatively simple uplift and fracture of the Miocene peneplain has to be considerably modified so as to include preliminary uplift, fracture, and erosion of an early Cretaceous peneplain along lines subsequently followed by the post-Miocene movements. Moreover, both these sets of movements would appear to have been influenced to an appreciable extent by the "post-Karroo" folds and fractures of about the middle Jurassic, as well as by still older structures.

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Old Shore Lines of Palestine.

By G. S. Blake.

THE object of this article is to bring up to date the known history of the earth's crust in the south-east Levant.

Cambrian rocks, consisting of a dark limestone with *Hyolithus*, have been discovered along the east side of the Dead Sea, but the base is not exposed. In South Palestine, in the Wadi Meneiaieh, the beds lie on a peneplain of the eroded igneous complex, and consist of red sandstone overlain by dark limestone with *Siphonotreta* and *Obolus*. East of Guweir grits and quartzites overlie and have suffered the same shearing as the igneous complex ; such shearing certainly does not occur in the strata of known Cambrian age. Near Rum the basal beds are undisturbed argillaceous grits which hold up the water collected in the overlying sandstone and give rise to springs. Ordovician and Silurian strata are unknown in Egypt, Palestine, or Syria, although the occurrence of Asaphid trilobites (east of the Lagoon, Dead Sea) is suggestive of a Lower Ordovician age. The nearest recognized Ordovician and Silurian strata lie in the Taurus Mountains. Strata with manganese ore, presumably of Carboniferous age, occur near Fenan, in Trans-Jordan, not far from the Cambrian, and at Wadi Meneiaieh, Palestine, are found lying unconformably on the Cambrian. Strata with an abundant fauna of Carboniferous age are preserved further south in Sinai, the most complete development being at Um Bogma, from whence the beds reach across the Gulf of Suez into the Wadi Araba area, where, according to Ball (1916),[1] they thin out.

The invasion of the granite (granodiorite) by the porphyry and later basaltic dykes is prior to the strata definitely known to be Cambrian, but the igneous intrusion below Nabi Hauran, which affects the lower sandstone beds and appears to form the southern end of the great Fenan porphyry dyke, requires investigation in this connection. The metamorphism of the granites in southern Palestine (Akaba), which has resulted in the formation of hornblende- and mica-schists, belongs to the Rift movement. In most parts unfossiliferous "Nubian Sandstone" lies directly on the igneous complex.

The section by Ball (1916) shows the Carboniferous strata lying horizontally on the peneplain of igneous rocks. Their undisturbed condition and lithology suggest shallow sea deposits resulting from isostatic movements of the crust or eustatic movements of the sea during Palæozoic times. Only after deposition of the Cretaceous-Tertiary formations, as for example in the sunken area of the Gulf of Suez, has folding occurred.

The Triassic formations again consist mainly of shallow water deposits (Hesban) with only sandy beds to the south (Zerka Main) (Cox, 1932).

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[1] See list of references at the end.

In Palestine there is only one locality in which Jurassic beds can be seen, viz. in the Wadi Hathira (Kornub), where 227 metres of marls and massive limestones are exposed without revealing the base. In Sinai, although there are many exposures of "Nubian Sandstone" lying on Carboniferous, only in the Wadi Mughara do marine beds with Jurassic fossils occur. The Jurassic shore appears to have lain to the south of Jebel Mughara, but the great thickness of 2,000 feet is suggestive of open sea to the north, with land over the whole of Arabia and southern Egypt (Moon and Sadek, 1921). The shore appears to have stretched to the east-north-east, with Kornub located some distance to the north-west, thence passing near the south end of the Dead Sea, whence it must have taken an irregular course to the north-north-east, for no Jurassic fossils have been found in the sandstone along the east side of the Dead Sea; these occur, however, along the Nahr es Zerka, where the strata appear to pass eastward into sandy fluviatile beds. It is also unknown how far east of Damascus Jurassic rocks occur below the more recent strata (Dubertret, 1933). The great thickness of marine strata at Mughara and in the Lebanon is in contrast with the comparatively thin deposits of Trans-Jordan and would indicate a very steep shore line.

Both in Nahr es Zerka (Trans-Jordan) and Kornub (Palestine) the highest Callovian beds are becoming sandy and there are no further marine beds in these localities until the Middle Cenomanian. Further north in Palestine there is evidence of transgression of the sea in Lower Cretaceous times, for in Wadi Farah and Hula two series of marine strata occur, one of Aptian age followed by sandy beds, and another of Lower Albian age; this is similar to the sequence in Lebanon. The shore line probably followed a curve nearly parallel with the old Jurassic shore, passing roughly around the present Judean Hills and along the west side of the Dead Sea. The stratigraphical evidence is shown in the table on p. 70.

Although the record is incomplete, it appears that, except for transgression on a north to north-east shore during the Triassic and Jurassic periods, south-east Palestine and Trans-Jordan were part of a land-mass which extended to the south-west through Sinai and across the Gulf of Suez, with the Arabian igneous massif forming the hinterland of the south-east.

The occurrence of gypsum deposits of considerable thickness in association with the Triassic beds of the Nahr es Zerka is of interest not only as indicating regression of the Triassic sea but also as denoting the position of an inland basin 10 km. east of the present Dead Sea depression.

In the northern part of Palestine the sequence shows shallow-water deposits of Lower Cretaceous age passing from thin limestone to calcareous sandstone or sandstone, overlain by the deposits of the main Upper Albian transgression by which northern Palestine was completely submerged. The sea does not appear to have covered Trans-Jordan until Upper Cenomanian times, after which, in southern Palestine and southern Trans-Jordan, there were still considerable oscillations of the shore line, as is shown by the table on p. 71

	Nahr es Zerka	Zerka Main	Akaba (Trans-Jordan)	Akaba (Palestine)
Lower Cenomanian. Vraconnian . Albian . . Aptian . . Neocomian . Kimmeridgian *to* Callovian .	Represented only by sandstone 1000 feet.	Represented only by sandstone.	Represented by unfossiliferous sandy formation.	Represented by unfossiliferous sandstone.
Callovian to Bajocian	800 feet of hard limestone and sandstone, marine.			
Triassic . .	Shales and gypsum	Shales and sandstone		
Carboniferous .	Not exposed	Not recognized.	Manganese ore with limestone and shales—Wadi Dana.	100 feet
Cambrian .		Black limestone.	Sheared quartzite.	150 feet.
Igneous peneplain	Not exposed.	Not exposed.	Igneous peneplain.	Igneous peneplain.

The gypsum deposit of the Kerak section appears to have its greatest thickness to the east of the Dead Sea area and it extends to within 5 km. of Kerak. The deposit thins out both north and south. In longitude it corresponds with the position of the Triassic gypsum. Below Masada in Palestine, at about the same horizon, are beds of gypsum only 2 to 3 cm. thick.

The relation between the Jebel Usdum salt and the overlying (? overthrust) anhydrite to the Triassic or Cenomanian-Turonian gypsum, and to the possibly Miocene beds spoken of below is uncertain (Lees, 1931).

Campanian-Maestrichtian chert beds extend right across southern Trans-Jordan to Jebel Tubaik in the extreme south of the

	Zerka Main	Ft.	Mojib	Ft.	Kerak	Ft.	Akaba Nagb (Trans-Jordan)	Ft.
Maestrichtian, Campanian, Santonian.	Limestone and chalk, flint and bituminous limestone, hard chalk . . .	600	Flinty limestone with phosphate . .	500	Flinty limestone and phosphate . Flinty limestone .	200 500	? Chert beds with interbedded marls and limestone, dolomite at base . Ochreous gypseous limestone . .	500 90
Turonian . .	Fine limestone, rubbly limestone and marls	400	White chalk, thin limestone and marls	200	Marly limestone and clay bed with *Chof-faticeras.*		Thin limestone and sandy limestone .	70
Upper Cenomanian.	White marly limestone with *Ostrea columba* Hard purple dolomite (100 ft.), marls and thin dolomite with *Ostrea africana*, *Strombus*, etc. .	300 200	Ostrea limestone, thin limestone and marls, red shales . . Gypsum, green marls, dolomite and marls	220 800	Gypsum (10 ft.), red shales, marls with thin limestone and *Ostrea columba*, dolomite (20 ft.), marls and green clays (30 feet).		Shales, limestone, and gypsum with *Ostrea olisiponensis* . Shales with *Ostrea africana* . . Dolomites and green shales . . .	280 200 50
Lower Cenomanian .	Greenish grey shales, marls, red, and yellow clay, white sandstone and gypsum . . .	50	Green marls . .	50	Sandstone.		Sandstone.	
Lower Cretaceous .	Sandy shales, white sandstone.		Sandstone.		Sandstone.		Sandstone.	

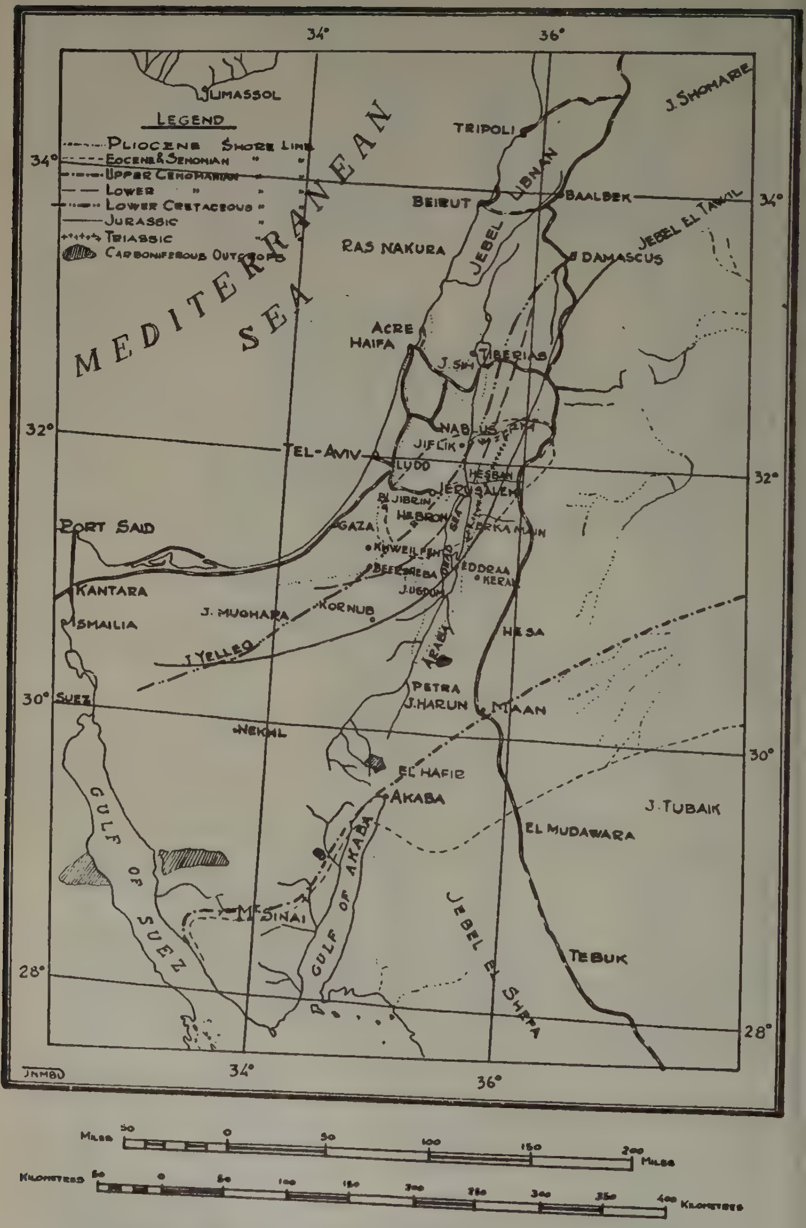

FIG. 1.—Sketch-map showing old shore lines of Palestine.

territory, where *Libychoceras ismaeli* (Zittel) occurs in them, and they pass up at Jebel Dawaimeh into marls and thin shales with *Cardita libyca* Zittel. They are overlain, as though by continuous sedimentation, by marls and flinty limestones of Eocene age; these carry (in the Maan area) occasional beds of crystalline limestone with Nummulites which Henson states are not referable to any species so far described from the surrounding regions. However, they are closely allied to *Nummulites fraasi* de la Harpe and are associated with a form related to *Assilina minima* de la Harpe. In Egypt the former species occurs (according to de la Harpe and Cuvillier) in the Lower Eocene of the Farafra Oasis, while the latter (according to de la Harpe) accompanies *N. ramondi* Defr. (= *N. globulus* Leym.) at Jebel Ter. Thus both forms suggest the Lower Eocene rather than a higher horizon, while the fauna of smaller foraminifera both to the west, and at Jaffar to the east, tends to confirm this conclusion. The Eocene beds thin out towards the south-east and are not found beyond the Akaba Nagb, which rises to 5,000 feet.

Similarly, in north-eastern Trans-Jordan, Senonian flinty limestones, overlain by limestone with nodular flints of Lower Eocene age, extend right over the plateau to the Iraq frontier.

The Eocene beds are of extremely uniform lithological character and thickness, being generally about 300 feet thick. An unconformity is visible between the Campanian chert and the Maestrichtian phosphates 7 km. east of Katrani.

In the Judean complex dome the cover of Senonian strata is entirely eroded in the centre. On the west flank at Har Tuv 300 metres of bituminous limestone with cherts were found under the Eocene strata; their base was not penetrated. Further west, however, the Senonian strata rapidly thin out. On the east flank, in the Judean wilderness, mottled beds, chert beds and bituminous limestone passing into chalk are met with in descending sequence (Picard, 1931), but in the Wadi Fusail bore, in the Jordan Valley, nothing was found 100 metres below the Lower Diluvial blue clay but bituminous limestone without chert beds, similar to that of Har Tuv. The occurrence of chert beds appears to be associated with conditions of emergence.

The presence of higher strata than elsewhere in the Danian of Nabi Musa, i.e. the mottled beds, may be explained by assuming their deposition by the last remnants of the retreating Cretaceous sea, but this would demand a fold along the Dead Sea area which might be expected to be traceable in the Eocene, whereas, actually, strata with an Eocene fauna do not occur until 20 km. to the north, and later evidence is rather in favour of land in this area. It should be borne in mind, however, that the mottled beds are only assumed—from association with the underlying bituminous limestone—to be of Danian age.

The existence around Bassa (Ras Nakura) and southward of chalk of Upper Eocene age (Henson), separated from the strata of Eocene age to the north (east of Tyre) by the "Ladder of Tyre" Cenomanian block, and from the Daylyat er Ruhah Eocene strata by the Carmel block, does not favour the existence of land as suggested by M. Avnimelech (1936).

In the western part of Palestine there appears to have been continuous sedimentation from the Eocene to the Oligocene, but the coarse blocks of material at Tel Duweir are suggestive of the proximity of sea cliffs, so that Judea may have already been hundreds of feet above the Oligocene sea (Blake, 1936). E. J. Daniel points out that the Oligocene of Deir Turaif (regarded by the writer in 1936 as Miocene), lying against Turonian–Cenomanian limestone, also indicates a fault of Upper Eocene to Oligocene age. Apparently the block type of structure was already in the making, succeeding the gentle folding already suggested from the thickening of the bituminous beds on the Har Tuv flank, but the question of the emergence of Judea and central Trans-Jordan, and also of parts of northern Palestine, during Eocene times, is still unsettled. Conglomerates at Beit Jibrin and below the nummulitic beds of Jebel Sih may represent oscillations of the shore line. It is significant that no definite Eocene beds occur around the Dead Sea from Jiflik southwards except the patch of supposed Eocene at Ed Draa.

The occurrence of Vindobonian beds (Blake, 1936) transgressive over the Eocene, and now raised to a height of 1,600 feet at Bir Khweilfeh, but not so far found in the Dead Sea area, is suggestive of continuous land from the west side of Judea across the Dead Sea, and including central Trans-Jordan. Whatever may have been the topography of the Dead Sea area, it is certain from the evidence given later that about the end of the Oligocene or the beginning of the Miocene period, a fault must have developed on the east side of the area in question sufficient to expose the top of the sandstone; its throw must have been about 1,000 feet if we assume complete erosion of the Senonian strata, or otherwise at least 1,500 feet.

In order to determine the various elevations during the Pliocene and Quaternary periods it will be more convenient to work backwards in geological history.

On the east side of the Dead Sea, above Zerka Main, is an old terrace with gypseous ochres and conglomerates which are intimately connected with the plateau which can be seen from the Zerka Main road before the final descent to the hot springs. The plateau lies 800 feet above the Mediterranean and roughly 2,100 feet above the Dead Sea. Most of the area is covered with gypseous sand, but hillocks, which appear to be sandstone, stand out like islands on the plateau.

At the Wadi from which the ochre occurrence was approached, the following sequence was seen :

	Ft.	
Above Mediterranean	850	
		Hard ferruginous conglomeratic sinter with gypsum.
	825	
		Brown iron ore.
Pliocene . .	820	
		Yellow ochre (calcareous).
	810	
		Hard limestone with clear flints.
Nubian . . .	700	
		Hard, white sandstone.

In the area where the Cenomanian limestones are present the following section can be seen :

Ft.	
1,400	
	Hard purple dolomite.
1,200	
	Fossiliferous marl beds with thin dolomite, *Ostrea africana* Lam.
980	
	Red and yellow marls and clays.
950	
	Soft white sandstone.
930	
	Red sandy gypseous shales
920	
	Red sandstone Plateau with ochre.
910	
	White sandstone.

It is evident that erosion of the soft sandstone by wave action along the shore of the old Jordan lake would quickly undermine the overlying Cenomanian limestones and bring about their collapse and disintegration and push back the cliffs along a shallow stretch of water. The later gypseous ochreous beds would be deposited during the desiccation of a lagoon separated from the main body of water by the general fall in level. The plateau which may mark the whole or part of the lagoon must have an area of at least 10 sq. km.

From similarity between these deposits and the gypseous ochres at Khan Hatrura it is difficult to avoid the conclusion that these beds belong to the same period of desiccation. Their altitude is about 1,000 feet above the Mediterranean. They indicate a differential movement of over 2,000 feet, made up of a rise of 800 to 1,000 feet on the edges of the uplift and a depression of 1,000 feet in the centre. It is impossible to say what depth the central part, which is now 1,300 feet below Mediterranean level had at that time.

E. J. Daniel, however, takes the view that Vindobonian beds occurring at 600 to 700 feet above the highest marine Pliocene nearby indicate a general rise in the " Mature Land " surface (Bailey Willis,

1928) to that amount after the Vindobonian and before the marine Pliocene, with the surface of the inland lake at about this level. In this case the Trans-Jordan terrace must have remained almost stationary, whereas the sandstone cliffs below, which are 2,000 feet high, and the 1,300 feet depression of the Dead Sea, must represent the succeeding movement.

The rift formation was followed by a period of enormous erosion indicated by the old filled-in gorge at Zerka Main which, after the rise in Diluvial times and subsequent fall in the level, has preferred to cut a new bed through the sandstone ; and in the Wadi Seial gorge on the Palestine side, which was excavated to about the present level of the Dead Sea, then filled with Diluvial detritus, and subsequently re-excavated during the post-Diluvial fall in the level of the sea.

The marine Pliocene of Galilee–Yizre'el appears to belong to a separate topographic feature. The enormously coarse breccias of the Wadi es Sherri are suggestive of a block to the south. These marine beds were elevated to 650 feet above Mediterranean level below Sarona (Galilee). They suffered great erosion and were-deposited as a breccia in the lower part of the Upper Pliocene (Blake, 1936, p. 17).

A section from the Gaza coast shows a gradual elevation of the upper marine Pliocene of 1,000 feet at Beersheba, but as shown by Blanckenhorn (1914), the lacustrine sandstone at Kornub stands at 2,000 feet as compared with similar beds at Ain Hosb at −300 feet. Thus a difference in elevation of 2,000 feet in Judea would correspond very much with the requirements for Bailey Willis's " Mature Land " (Bailey Willis, 1928).

In the Kornub area the country to the east descends to the level of the Wadi Araba area in a series of steep monoclines. In the main block which forms Judea the dips of the strata by no means correspond with a simple mountain fold ; often the inclination is towards the centre, the main uplift being block-wise and the flanks terminating both on the west and the east in steep faulted monoclines which frequently turn inwards and die out, recommencing on a parallel line. The position of the younger strata in the troughs is also adjusted by steep dips which reverse before giving another plunge downwards. Generally a steep monocline represents a glide plane rather than a normal fault.

The monocline structures must therefore be due mainly to upthrust of the Judean block in the last rift movement. The additional sinking of the trough has produced clean faults in the Dead Sea basin but not everywhere. The continuous lesser folds which can be traced in a south-south-west—north-north-east direction probably belong to Eocene–Oligocene movements.

The occurrence of transgressive Vindobonian on the south and west of the Judean block (Blake, 1936) and south of Carmel (Avnimelech, Doncieux and Picard, 1936) indicates a sinking of the existing land surface on the west either by warping of the surface or by tilting of the Judean block. As, however, the thickness is not great, uplift in accordance with the general trend must soon have followed. The lower marine Pliocene occurs only in the Beersheba embayment and west of the Shephela (Blake, 1928). The lower marine Pliocene of the coastal plain is followed by forest growth (Qalmanya, etc.) and the marine Pliocene inland (old Galilee lake) is followed by conglomerates and sandy beds of Upper Pliocene age. The Dead Sea lake area shows Upper Pliocene sands of extensive distribution with evidence of low land and shallow water. They are found as high as Bethlehem below the " nari " crust.

In Trans-Jordan there are not sufficient details to get a clear view of the geological history. However, the plateau type of country of southern Trans-Jordan is suggestive of its having been at a much lower altitude in comparatively recent times, and the steep dips of the Pliocene beds at Utlak and Ed Draa are indicative of much movement. These beds extend up to Mediterranean level along the Wadi Araba. They contain abundant sand beds, limestones and flint gravels, but no igneous rocks, whereas the Diluvial beds contain, in addition, igneous detritus. The great porphyry dyke at Fenan rises over 2,000 feet, and this would also necessitate, for its exposure to erosion, a movement equivalent to that which took place in Judea between the deposition of the Pliocene of Jebel Usdum and of the Diluvial deposits (Blake, 1930).

Whether the uplift from south of Jebel Harun to El Hafir (south of Maan) was greater than towards the north, or whether it always stood at a higher altitude, with a drainage to the Dead Sea area, cannot at present be determined.

From the above data it is possible to arrive at the conclusion that Judea with most of its present-day mountains and steep valleys stood at a maximum elevation of about 1,000 feet in Pliocene times. At least 600 feet of Senonian strata in the centre of the arch and 500 feet of Cenomanian had already been removed by erosion. We may assume that the eroded material was largely carried westwards, but, though conglomerates of definite Miocene age are known, they do not account for the great mass of eroded limestone.

In Upper Pliocene times the low hills were surrounded by shallow expanses of brackish to fresh water, which were thickly laden with sands from the Nile along a belt which reached from Mughara to the west flank of Judea, sweeping inland along the Beersheba Gulf.

The entire erosion of the Senonian in the central block and its preservation in the eastern parts demands much less exposure to erosion and, consequently, a much lower relative altitude, especially of the Mount of Olives Senonian beds, before the last rift movement. The preservation of the Senonian–Danian strata in the Dead Sea area also requires lower elevation, which necessitates a drainage to that area, but no evidence of Miocene deposits has so far been discovered. It might possibly be assumed (Wyllie, 1931) that the lower Jebel Usdum beds belong to that age; the enormous thickness of conglomerate beds which lie on edge below Ed Draa and form the lower beds of the Usdum series does, in fact, suggest that the Dead Sea area had long been a basin for the drainage of Trans-Jordan and eastern Palestine.

It would be interesting to have more detailed information on the age of the erosion of Jebel Mughara, which is the only dome structure from which the whole of the Cretaceous beds, elsewhere about 6,000 feet thick, has been denuded.

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On a Freshwater Shale with *Viviparus* from Johore (Malay States).

By L. R. Cox, Department of Geology, British Museum (Natural History).

(PLATE III.)

THE fossiliferous rock now reported upon has been submitted to me by Mr. E. S. Willbourn, Director of the Geological Survey of the Federated Malay States, in the hope that examination of the fossils might lead to some definite conclusion as to the age of the coal-bearing strata with which it is associated. The locality is Durian Chondong, Kepong, in the Unfederated Malay State of Johore, and the material examined comprises a number of bore samples obtained from depths varying from 88 feet to 145 feet.

These all consist of a grey marly shale containing numerous fossil shells, mainly more or less crushed, but sometimes well preserved and even retaining traces of their colour-ornamentation. The only other fossils obtained from the samples, beyond a few obscure plant impressions, are some small and indeterminate fish teeth.

All the shells, except for one specimen of a small ribbed gastropod described below as *Thiara* ? sp. indet., appear to be referable to a single species of the genus *Viviparus*, whose presence indicates beyond any doubt that the deposit is of non-marine and probably lacustrine origin. Unfortunately, this species, which is so abundant, and is described below under the name *Viviparus willbourni*, cannot be identified with any form previously known, and in view of the long range of its genus (Jurassic—Recent) gives no information as to the age of the deposit. The fairly fresh state of preservation of the shells suggests, however, that the age is not older than Upper Tertiary. Mr. Willbourn suggests that it is probably Upper Miocene, and may well be correct.

It may be noted that, while no comparable Neogene freshwater formations with *Viviparus* have been found in Sumatra, Borneo, or other islands of the East Indies, such deposits are fairly widespread on the mainland of south-eastern Asia; for example, in Tenasserim (Annandale, 1923) and in the Northern Shan States of Burma (Annandale, 1919), in Tonkin (Mansuy, 1919, p. 182; Patte, 1927, p. 105), and in Yunnan (Mansuy, 1918). In none of these areas is the age of the beds known with any precision.

Description of the Species.

1. *Viviparus willbourni* sp. nov.

(Plate III, Figs. 2–8.)

Specific Characters.—Moderately large for the genus, the largest specimens attaining a height of about 35 mm.; of somewhat variable although usually of medium acuteness, with an average spire angle of about 45°–50°. The whorls number about six to seven, of which the first four form a blunt, papilliform apex to the conical body of the shell. The nuclear whorl is small and obtusely rounded, the next three moderately convex, and the later ones very feebly convex or even flat, tending to become slightly shouldered below the suture; the periphery is evenly rounded. The third and fourth whorls bear a delicate ornamentation of fairly regularly and closely spaced raised growth-threads, but the later whorls are smooth, except for occasional and less conspicuous growth-threads; these are slightly sinuous, but in general direction are inclined so as to make an angle of about 60° with the suture.

Material.—The holotype (British Museum, Geol. Dept., G. 60704, Fig. 7), selected as being the least crushed specimen of its size, and a considerable number of other specimens, mostly indifferently preserved and incomplete, but including several uncrushed specimens of the apical whorls.

Dimensions.—The measurements of the holotype and of a somewhat larger, although crushed, paratype (G. 60709, Fig. 8) are as follows:—

	Holotype. mm.	*Paratype.* mm.
Height . .	26·5	33·0
Diameter .	18·0	24·3

Comparison with other Species.—This species is certainly distinct from any now living in the Malay States or adjacent areas. It agrees closely with *V. margaryaeformis* Mansuy (1918, p. 3, pl. i, figs. 1–7; pl. ii, figs. 1–3), from the Neogene of Yunnan, both in general shape and in its papilliform apex. The species in question attains, however, a larger size than any of the specimens now described, while its earlier whorls have not the delicate ornamentation of raised growth-threads described above. In view of these differences it appears advisable to regard the two forms as distinct. The two fossil species of *Viviparus* from Tenasserim described by Annandale (1924) are smaller than the specimens now described and have not a comparable papilliform apex.

Occurrences.—At all depths from 88 feet to 145 feet; the holotype comes from a depth of 98 feet in the borehole recorded as "4 G".

2. *Thiara* ? sp. indet.

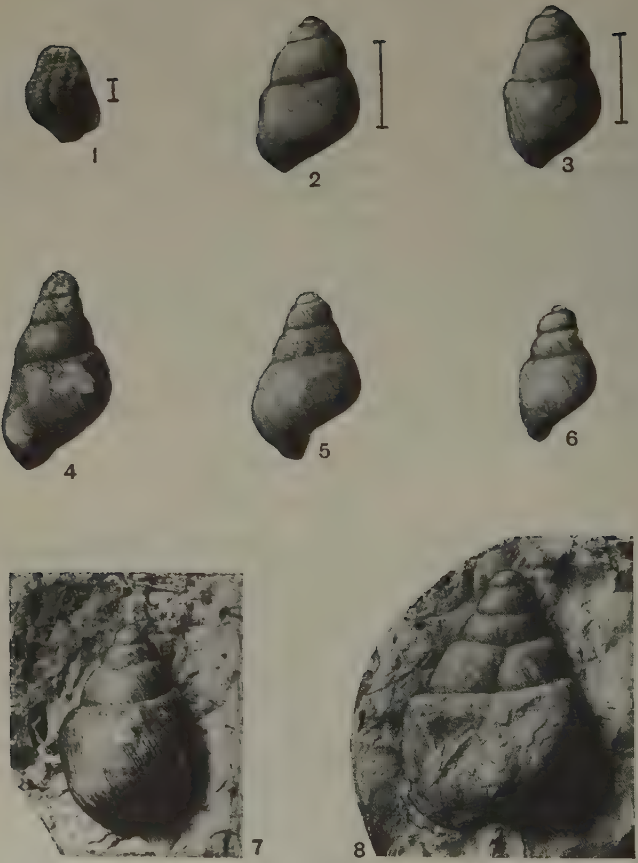
(Plate III, Fig. 1.)

Material.—A single fragmentary specimen (British Museum, Geol. Dept., G. 60716) with both its apex and peristome broken away.

Description.—The shell is very small, its original height, allowing for the missing apex, having been approximately only 3·5 mm.; whether it is full-grown it is, however, impossible to say. The spire angle appears to have been about 45°, the spire occupying about one-half of the total height of the shell. The whorls are of moderate convexity, the last evenly rounded at the periphery. The sculpture consists of rounded axial ribs with a slight sigmoidal curve and retrocurrent inclination, separated by rather wider interspaces, and crossed by subordinate rounded, slightly undulating spiral bands which are separated by narrow, almost linear interspaces; the uppermost spiral is slightly more prominent than the remainder, forming a sutural band. On the last whorl the axial ribs number thirteen and the spirals ten; of the latter, the top four are visible on the earlier whorls.

Remarks.—Although very small, this shell appears to belong to some genus of the Thiaridae, and so is referred, with a query, to *Thiara* (*sensu lato*). It may belong to *Melanoides*.

Occurrence.—At a depth of 99 ft. 6 in., in the borehole recorded as "4 G".



FRESHWATER GASTROPODA FROM THE NEOGENE OF JOHORE.

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EXPLANATION OF PLATE III.

Fig.

1.—*Thiara* ? sp. indet. (× 4). Depth of 99 ft. 6 in., borehole "4 G" at Durian Chondong, Kepong, Johore. [Brit. Mus., G. 60716.]

2.—*Viviparus willbourni* sp. nov., apical whorls (× 1¾). Depth of 94 feet, same borehole. [Brit. Mus., G. 60714.]

3.—Same species, apical whorls (× 1¾). Depth of 98 feet, same borehole. [Brit. Mus., G. 60707.]

4, 5.—Same species, half-grown specimens (nat. size). Depth of 98 feet, same borehole. [Brit. Mus., G. 60705–6.]

6.—Same species, apical whorls (nat. size). Depth of 143 feet, borehole "5 G" at same locality. [Brit. Mus., G. 60710.]

7.—Same species, holotype (nat. size). Depth of 98 feet, borehole "4 G". [Brit. Mus., G. 60704.]

8.—Same species, large, crushed specimen (nat. size). Depth of 96 ft. 6 in., same borehole. [Brit. Mus., G. 60709.]

The Age of the Norwich Brickearth.

By Kenneth Harrison.

FOLLOWING the original suggestion of Searles Wood, the Norwich Brickearth has been referred to the same phase of glaciation as the Basement clay of Holderness, which in turn has been correlated with the Scandinavian Drift of Durham. Recent work by Stather (1929) and by Bisat (1932, 1935) shows, however, that the Basement clay of previous authors (Wood, Lamplugh, Reid, and others) may be resolved into a drift (*a*) of Scandinavian origin, together with (*b*) deposits of separate derivation; and the time now seems appropriate for a critical examination of the position of the Norwich Brickearth in the glacial sequence.

In 1908 Harmer collected a number of boulders from the Brickearth, and these were examined by Dwerryhouse, who reported the presence of Whin Sill dolerite, porphyrites of the Cheviot type, and Carboniferous Limestone containing foraminifera and other small fossils. Rhomb-porphyry has been found in the Brickearth at Sprowston (Boswell, 1923), but it cannot be said that Scandinavian erratics predominate there. Pebbles of foreign rocks are not easy to find in the sections at present exposed in the Sprowston brickyards, but occur in rather larger numbers embedded in the cliff at Corton (Suffolk), where the Brickearth is succeeded by Middle Glacial sands and finally by Chalky-Kimeridgian boulder clay. Mr. Sidney Melmore has kindly examined some of the boulders collected from this exposure and supplies the following notes :—

" The collection consists of one compact greenish-coloured sandstone, two black silicified mudstones, a pisolite, and three silicified oolites ; one green phyllite ; a fragment of flesh-coloured massive orthoclase, one grey biotite-granite, one hornblende-granite, one hornblende-syenite, a chloritized orthophyre, one hornblende-andesite ; a porphyrite, a tuff and a volcanic breccia, all three of Cheviot type ; and one bluish-green volcanic ash.

" None of the rocks is sufficiently distinctive to make specific identification possible, even in thin sections ; but all except the syenite may well be of British origin. The collection also includes three pebbles of Carboniferous Limestone."

The assemblage from Corton, so far as it goes, confirms the findings of Harmer and Dwerryhouse, and the situation appears to be not unfairly summarized by the words of Boswell (1914) : " It is well known that the Lower Glacial beds of the coast and inland sections of Norfolk are especially characterized by the presence of boulders of igneous rocks, some of which are Scandinavian : abundant dolerites, from the Whin Sill (?), Cheviot rocks, and, very rarely, boulders of Lake District origin also occur." And therefore, it is remarkable that Trechmann (1915), discussing over 500 specimens from the Scandinavian Drift at Warren House Gill (Co. Durham), could write : " Neither the red porphyries, nor the variously coloured rhyolitic fragments, the only forms that might be identified with well-known North of England types, bear any close resemblance to Cheviot or Lake District volcanics. . . . I regard all the travelled stones in this bed as of Scandinavian origin." Four years later (1919, p. 185) he said : " . . . in the Durham Scandinavian clay I have repeatedly searched, but without success, for English rocks other than quite local Permian material. It is a ' pure culture ' of Norwegian stones, no trace of Cheviot, Carboniferous Limestone, or Whin Sill is to be found in it."

Again, Stather (1929) discussing the character of the Basement clay of Holderness, commented on " the total absence, or extreme rarity, of many common British rocks which abound in the Upper clays " : and in the course of several visits to the Dimlington sections a prolonged search has failed to reveal any recognizable specimens from the Lake District or Scotland, distant British outcrops being apparently represented only by fragments of Magnesian Limestone (as in Trechmann's exposure) and, very rarely indeed, a pebble of fossiliferous Mountain Limestone, although this latter rock is perhaps the commonest erratic in the succeeding beds (see also Kendall and Wroot, 1924).

It seems clear that North British rocks ought not to be more abundant in a Norfolk drift than in a Durham or Holderness deposit of the same age and origin ; but fortunately a way of escape from this paradox is provided by the work of Bisat (1935), who has shown that the Basement clay is succeeded by a lead-coloured series, which he terms the Drab, abounding in rocks from Scotland, the Lakes, and from Carboniferous sources, together with laurvikite, rhomb-porphyry, and other Norwegian types. The Drab clay has more than once been mentioned under the title of "Upper Basement" (e.g. by Raistrick, 1929 ; cf. Kendall and Wroot, 1924), but Bisat has pointed out that it is a distinct and very persistent bed in Holderness. The so-called Basement clay of Sewerby may possibly be included in this series: Lamplugh (1889) collected from Bridlington boulders which Harker identified as being of Scottish (Cheviot in particular) and of Carboniferous derivation, and similar erratics may be gathered in great numbers from the sections now exposed in Bridlington Bay. It is very probable that the westerly component of the Drab series is represented by the boulder clay which Trechmann (1919, pp. 191, 193) found in the dock excavations at Hartlepool, which contained Shap Granite and other western erratics ; and this he referred to an age intermediate between the Scandinavian and the Main Cheviot drifts of the Durham coast.

The southward prolongation of the Drab clay of Holderness would yield precisely those erratics which have been found in the Norwich Brickearth, whereas a similar extension of the Basement clay would not ; it is suggested, therefore, that the earliest known beds in Norfolk of direct glacial origin are of the same age as the Drab of Holderness, and that the true Scandinavian Drift of Dimlington and Durham still remains to be recognized in East Anglia. The results may be tabulated thus :—

East Anglia	*Yorkshire*	*Durham*
Norwich Brickearth	Drab series	Hartlepool boulder clay
—	Basement clay of Dimlington	Scandinavian drift

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The Compression and Stretching of Continental Layers.

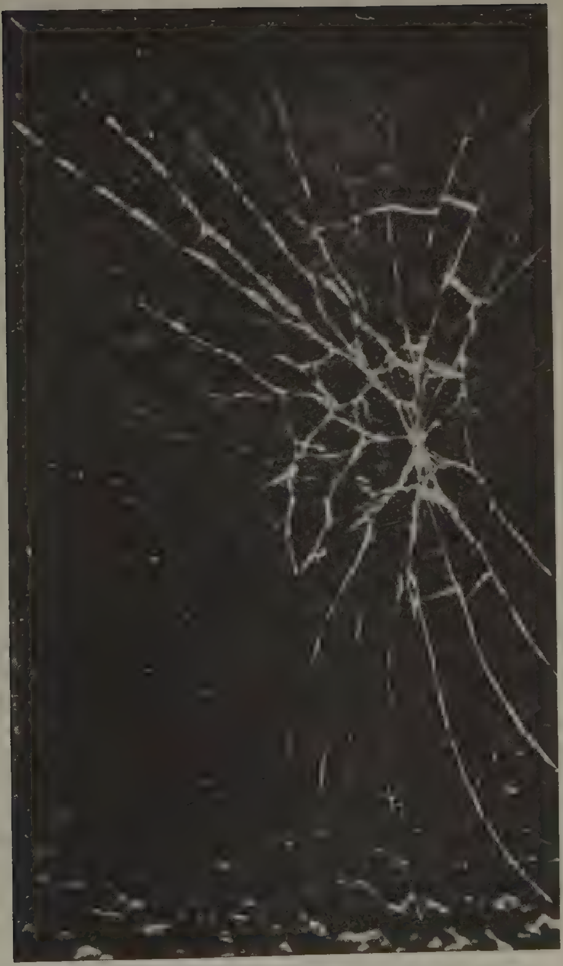
By P. R. Thompson.

(PLATE IV.)

THE forces which produced the folds of the Alps, and caused waves of compression to be transmitted as far as the Weald, may have been sufficiently powerful to start a drift displacement of Europe towards the north-east. As there does not appear to have been any similar compression in North America, a north-easterly movement of Europe would have caused shear in the strong continental layers which are considered to have connected the two continents. Tensile stresses would probably have arisen in these layers, unless the layers had begun to thin out before the state of tension was reached. There would have been a limit to the extent to which thinning could have proceeded, since a certain thickness of rock would have been needed to produce the necessary stress-differences. This thinning out process may have come into operation, except in a number of kilometres immediately below the surface, where tensile stresses may have arisen as drift continued. Under these circumstances the uppermost part of the crust would have sagged upon the thinning region, and been broken up by a system of tension fractures.

The nature of a system of tension fractures associated with sagging may be illustrated by the simple experiment, the result of which is depicted in the accompanying plate. The material used was a sheet of glass having an uneven surface on one side. The cracks, which correspond to fractures in a region of subsidence, were produced by the application of pressure over a small area of the plate: they resolve themselves into radial and concentric systems. Some radial cracks extend much further than the outermost crack of the concentric system. In and near the area to which pressure was applied the majority of the cracks follow the depressions in the glass, but in other places they show complete independence of both elevations and depressions, a respect in which they resemble the long fractures which sometimes traverse mountainous districts without relation to the strike of the ranges. Some of the smaller cracks do not pass completely through the glass, but open into the side remote from that to which pressure was applied, thus giving some indication of the distribution and nature of the stresses between the surfaces of the plate. With increasing radius the concentric cracks gradually cease to present the appearance of closed curves, and degenerate into one or more arcs, which usually terminate on radial cracks. Groups of small cracks often spring from the radial cracks: these always diverge with increasing distance from the centre of disturbance. Any apparent exception to this rule is found to be a case where a short crack of the concentric system joins a radial one.

The arrangement of cracks described above bears some resemblance to the dominant lines of the channels of the Arctic Archipelago,



CRACKS PRODUCED BY APPLYING PRESSURE TO ONE SIDE OF A GLASS PLATE.

the coasts of Greenland and North America, and the western edge of the continental shelf of Europe. Assuming that the Alpine foldings were accompanied by stretching and subsidence in the way described in a former paper,[1] strand-lines throughout the world may have fallen as much as 200 metres, allowing for isostatic adjustments. Subsidences of this kind may possibly account for the rate at which shallow seas retreat from the land. This rate is rapid in comparison with the extremely slow rate at which transgression normally proceeds. In this way dry land may appear in regions where no elevation, except perhaps an isostatic one, has taken place, as well in places which have experienced orogenesis.

If a displacement of the kind described actually took place, North America may have been dragged to the north far enough to close any channel which formerly separated this land from Asia. The subsidences which led to the extension of the Atlantic Ocean may first have brought to a close the period of striking resemblance of the deposits of the West Indies to those of the same age in the south of Europe.[2] After some time the Arctic Ocean may almost have been converted into a lake, separated from the Atlantic by ridges extending across the ocean and nearly preventing communication between the waters to the north and south. A flow of water to the south may have taken place, since the amount of precipitation from the atmosphere over the Arctic regions may have exceeded the amount of water lost through vaporization, and since the amount of water returned to the oceans as a whole could not have been greater than the amount lost in the form of vapour. As the almost isolated body of water cooled, and the cold water spread to the south, a migration of faunas may have taken place. A state like this may have been reached in the Pliocene period, when numbers of northern immigrants, up to that time foreign to the Mediterranean, began to make their appearance in that sea, while at the same time the number of representatives of warm seas was reduced.[3] The approach to cold conditions must have been slow, since the northern species increase in number very gradually in the English Crag.

The processes of elevation of the land, continental drift, and the depression of the strand due to subsidence, may have caused the spatial relations between land and water, and the meteorological conditions resulting therefrom, on several occasions to approach, and later to depart from, the critical state necessary for the onset of a glacial period.

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[1] P. R. Thompson, "Thermal Contraction, Land Bridges, and Geosynclines," GEOL. MAG., 1935, LXXII, 377–80.

[2] E. Suess, *The Face of the Earth* (*Das Antlitz der Erde*). Translated by Hertha B. C. Sollas. Vol. i (1904), p. 350.

[3] *Op. cit.*, p. 353.

Postscript Notes on the Ballard Down and Ridgeway Faults.

By W. J. Arkell, New College, Oxford.

I. The Ballard Down Fault.[1]

MR. BRYDONE'S letter in the Geological Magazine (1936, p. 329) provides an opportunity to make some postscript remarks on this subject. In addition I have received letters from Mr. H. J. Osborne White and Mr. F. W. Shotton, containing stimulating criticism and suggestions, and I am grateful to them for allowing me to quote from what they wrote.

Mr. Brydone asks if I have any evidence that where the "Purbeck" Fault reaches the foot of Ballard Cliff the chalk south of (below) the fault is younger than that north of (above) it. Mr. Shotton had asked me the same question; for, as he points out, Strahan's southward thrust is only possible if all the beds above the fault are younger than all those below. I have no new evidence. The assertion is due to Strahan himself, who stated in his Memoir (1898, p. 217): "It is true that this newest Chalk [' the vertical strata under the fault '] is actually surrounded on every side by older rock." While sceptical of the feasibility of proving this statement, in view of the discouraging state of the compressed chalk immediately under the fault, I took it over from Strahan perhaps rather too readily, realizing it was fatal to his theory of a southward overthrust. At the same time I qualified it by adding "but the differences in age are very slight, for the fault-plane lies wholly in the zone of *Belemnitella mucronata* (Rowe, 1901, pp. 32, 36)".

Strahan in turn had adopted the idea from Barrois,[2] who definitely showed a triangle of *mucronata* chalk below the fault, surrounded right and left by older, *Marsupites*, chalk. Rowe (1901, op. cit., p. 36) corrected Barrois's reading of the zones, but he did not contradict Strahan's statement. His omission of any comment on such an all-important application of his zoning work, coupled with the long verbatim quotations from and approving references to Strahan's account of the section, left me with the impression that Rowe still accepted the idea, although in modified form. It would probably be better, however, to regard it as no longer a justifiable notion, it having arisen out of Barrois's misinterpretation of the section, and having been robbed of any validity by Rowe's correction of Barrois's reading.

Mr. Brydone rightly draws attention to the almost unaltered condition of the chalk in Studland Bay and the unshattered condition of some of the fossils in it. He considers this fatal to my explanation of the faulting because such chalk could not have "had a series of bendings to and fro passed through it as postulated by Dr. Arkell's theory". I presume he is here referring to the glacier-like movements of the downthrown chalk over the curve in the fault-plane, as described on my pp. 61–2. The effects of such movements, however, cannot be compared with the enormous compressive forces and strains set up in the vertical limb of the anticline during the formation of the fold. The contrast presented by the indurated and sheared chalk of the vertical limb of the fold as seen south of the fault, and the relatively unaltered chalk to the north of it, was already pointed out by Webster (1816, op. cit.,[1] p. 168) and emphasized by Strahan (1898, p. 170). According to Rowe (1901, p. 37) the chalk north of the fault to Handfast Point and Studland is intermediate in condition between that south of the fault and that in the undisturbed basin about Wool: "It has been compacted considerably . . . All large fossils are broken, and a perfect Echinid is a great rarity." The only source of such chalk in such quantity seemed to me to be the top of the anticline; and the movements required to bring it into its present position seem of the right order for altering the chalk slightly as described by Rowe, with "small faults and occasional slickensiding".

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[1] The name Purbeck Fault is now dropped because objectionable, for reasons explained in my previous paper (Geol. Mag., LXXIII, 1936, 56–73, 97–118). What earlier authors meant by the Purbeck Fault everywhere except at and near Ballard Down, Swanage, was the Purbeck Fold.

[2] Ch. Barrois, 1876, *Recherches sur le Terrain Crétacé supérieur de l'Angleterre et de l'Irlande*, p. 102, pl. iii, fig. 7.

It is possible to land from a boat and climb up a landslip close to the fault cave to study closely the curved part of the chalk north of the fault. A recent re-examination of this curved portion satisfied me that there is no essential difference in hardness and alteration between it and the horizontal chalk to the north of it, but the greatest possible contrast with the vertical rock to the south. If the chalk can be bent so far without serious alteration there seems no reason why it should not be bent back again without suffering worse damage.

The condition of the chalk in the cliffs north of the fault has been cited as an additional confirmation of my hypothesis by Mr. Osborne White. He wrote me as follows (28th April, 1936): "The relevant phenomena you mention were duly noted down by me when I inspected the cliffs in 1895, some time before the reading of Strahan's 'Overthrusts' paper of that year. I further noted that, northward of the fault-cave the chalk quickly assumed 'the character of ordinary Upper Chalk'—as it ought, according to your views, since it at one time formed part of a region of the fold *a priori* not liable, or (remembering the superior axial region) less liable, to suffer 'packing'. *Ex hypothesi*, the fault cut through the body of packed chalk and carried part of it away northward and downward. The transported part—with its symptoms doubtless aggravated or complicated by the journey—would be easy to recognize were any of it exposed, but I neither noted nor can recall any feature suggestive of it towards Studland : it has gone too deep, I suppose. If confirmed, the absence of this detached piece of 'packing' from the Ballard-Studland range of cliffs indirectly affords the minimum measure of horizontal displacement allowable to the fault on this line of section, and is in keeping with the conditions represented in your fig. 2 (Geol. Mag., LXXIII, 62)."

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[1] References at end of my previous paper.

I should like it to be clearly understood, however, that I am far from insisting that I have found the right solution to this extraordinary fault. Any alternative suggestion would be most welcome. I therefore regret very much that I am unable to understand Mr. Brydone's hypothesis ; probably owing to his attempting to compress it into a single sentence of seven lines, containing five "which"-clauses and only two commas. So far as I can construe that sentence, it seems that we agree that the fault is a downthrow north and that the upward curve in the chalk above the fault-plane is due to drag (in the sense of adaptation to the curve of the fault-plane) ; but I am puzzled by the reference to the "opening of the fault in the final stage", and its having "preserved the chalk which supports the Tertiaries . . . from being involved in the upthrust to [on ?] the south". Is he reverting to some form of Clarke's northward underthrust hypothesis, evolved just a century ago ? That hypothesis is in some ways attractive, and it has a theoretical advantage over Strahan's southward overthrust, in the direction of the movement postulated, but it seems highly improbable.[1]

An observation made on my recent visit to the section seems worth putting on record ; it is that for a depth of 2 or 3 feet immediately under the fault-plane the earlier inclined shear-planes and vertical bedding-planes are bent back southwards a small but definite amount. At first sight this seems to favour Clarke's and Strahan's thrusting hypotheses ; but on reflection it will be seen that it has if anything the opposite significance. The fault-plane being a curve, if the chalk above it travelled downwards, the force exerted by the down-travelling block would have a powerful southward component, which would bend the truncated edges of the vertical chalk below in just the way that they are observed to be bent. The line of fracture being extremely clean (more a shear than a fracture), the two components of the force would have clearly demarcated effects. The whole mass must have been under high gravity pressure to be so cleanly sheared, and consequently the truncated edges of the vertical chalk would have had no chance of being bent round towards the north and dragged down in the ordinary way. On the other hand, if the movement above the fault-plane had been a thrust upwards and southwards relative to the vertical chalk beneath (as postulated by Clarke and Strahan), the southward deflection of the ends of the vertical chalk under the plane might be expected to have been much greater and less superficial. Also it might be expected that shear planes would have been formed, sloping upwards and southwards from the under side of the fault-plane.

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[1] Clarke, W. B., 1837, "Illustrations of the Geology of the South-East of Dorsetshire," *Mag. Nat. Hist.*, N.S., i, 414–421, 461–9.

With regard to the other points raised by Mr. Brydone, I cannot agree that " any dip visible in Studland Bay " is due to a system of north-south axes. Only the slight westerly element in the dip can be due to such axes. The dip of the Tertiaries is difficult to measure accurately, owing to false-bedding and slipping, and the irregularity of the junctions between Chalk and Reading Beds and between Bagshot Sand and Bagshot Clay. The latter junction at Redend Point, Studland, however, seems to me to dip at 8 to 10° a little west of north. This is a steeper dip than that of the practically horizontal chalk between the Ballard Down Fault and Handfast Point, but it is still small and shows that the fault-plane under Studland Bay (if my hypothesis is correct) must be nearly straight, as postulated on my p. 61 and below fig. 2, p. 62.

Incidentally, the condition of the Bagshot Beds at Studland suggests that they may well have undergone a certain amount of movement beyond mere elevation and simple tilting.

II. THE RIDGEWAY FAULT.

In July, 1936, it was possible to make some new observations on the Oxford Clay " dyke " in the Ridgeway railway-cutting. Slipping of the clay on the west side of the cutting, which began again over two years ago, became serious during the past wet winter, and for a time the up-line was blocked. The slipped material has now been removed, leaving a better exposure than has been seen, probably, since the original sloping and grassing were completed. The Oxford Clay is bared, though more or less shifted by the slipping, for a length of about 45 yards, up to the junction with the Wealden, and to within about 10 feet of the Chalk. At the north end can clearly be recognized the Red Nodule Beds of the uppermost Oxford Clay of the coast sections, grey clays with red and grey " kidneystones ". I collected—

Cardioceras cf. *costellatum* Buckman (as on the coast).
Gryphaea dilatata J. Sowerby (fragments abundant, some much bored).
Lopha gregarea (J. Sowerby).
Procerithium sp. (several, in a kidneystone).
Serpulae.

These beds occupy about half of the exposure. The southern half consists of black sandy clay of quite different appearance, with harder bands of sandy, soft marlstone, weathering brownish, obscurely " fucoidal ". These appear to represent the lower part of the Nothe Grits, which are known to begin to pass into clay westward from about Jordan Hill. I collected casts of *Modiola bipartita* J. Sowerby, *Pleuromya alduini* (Brongniart), and a clavellate *Trigonia.* They are unlike any true Oxford Clay exposed in the neighbourhood. From here probably came the " *Ammonites perarmatus* (*catena*) " identified by J. de C. Sowerby (see Strahan, 1898, pp. 22, 225).

Towards the north end of the exposure the beds of kidneystones and the red colouring associated with them seem to stand nearly vertical, but with some dip to the south.[1] Although such indications are untrustworthy it is interesting to be able to establish at least that there is an upward succession from north to south.

Part of the clear-cut junction with the green Wealden clay was visible, but I could find no trace of any Cornbrash. On the other hand the lines of kidneystones (cementstone concretions) which seemed to stand nearly vertical at the north end of the exposure suggested the highly inclined line of nodules shown in O. Fisher's drawing at *d* (reproduced in Strahan, p. 225). Many of the nodules are light grey, not red. Can it be that these were " what appeared to be nodules of Greensand " to Fisher ? Other pieces of cementstone, undoubtedly from the Oxford Clay, are angular and partly decayed, with rough surfaces, partly composed of Serpulae and oyster-fragments, and by their red colour might have suggested Cornbrash to C. H. Weston ; but I saw none large enough to be called " blocks " (see Bed 23 of Weston's section, in Strahan, p. 224), and they are in the northern half of the exposure, not at the south end as are the Cornbrash blocks indicated in Weston's drawing.

Since none of the fossils originally collected at Ridgeway seem to have survived, a set collected in July, 1936, has been presented to the Geological Survey Museum.

ERRATA, ETC.

The following misprints occur in my previous paper. All but one were corrected in time to prevent their appearance in the reprints.

p. 58, Text-fig. 1 (Expl.), for *Rowe, 1931*, read *Rowe, 1901.*

p. 99, line 9 from bottom, for *north-north-east* read *north-north-west.*

p. 103, Text-fig. 6A (Expl.), for *p. 99* read p. *101.*

p. 108, para 2, line 2, for *west* read *east.*

It should, perhaps, also be mentioned that the dip-directions given on pp. 101, 103 were magnetic. The variation was 12° 16′ W.

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[1] Professor A. Morley Davies visited the cutting in August and estimated the dip at 70° S.

A Preliminary Note on the Geology of the Bristol Channel Islands, Steep Holme, Flat Holm, and Denny Island

By Stanley Smith and Gerald R. Willan.

DURING the last two or three years we have been mapping and working out the geological structure of the small islands in the eastern part of the Bristol Channel. Visits to these can only be made periodically, and our work is thus likely to extend over some considerable time. We consider it desirable, in fairness to other workers and to those interested in the Lower Carboniferous rocks, to publish the main facts as far as we have established them, leaving details and any discussion until the work is completed.

The most southerly of the islands is Steep Holme, which lies about 5 miles west of Weston-super-Mare, or 3 miles W. by N. of Brean Down, the nearest point of the mainland. It measures slightly more than ½ mile from east to west, but only 350 yards from north to south in the widest place. The highest point of the island is 256 feet above O.D. Flat Holm lies about 3 miles N. by W. of Steep Holme, somewhat nearer the Welsh than the Somerset coast, being 3 miles S.E. of Lavernock Point, Glamorganshire. It is somewhat rectangular in shape, measuring about 550 yards from east to west by 600 yards from north to south, the highest point being 96 feet above O.D. Denny Island lies in the middle of the channel opposite the mouth of the Avon, about 17 miles N.E. of Flat Holm. It is only 100 yards long, 50 yards wide, and 21 feet high.

Flat Holm is formed entirely of beds of the Syringothyris Zone. These include the upper part of the Caninia Oolite (C_1), the lower part of C_2, and probably higher beds, but the thickness of strata above the Caninia Oolite is insufficient to reach the base of the Seminula Zone. C_2 contains a lagoon phase including a conspicuous gasteropod bed. The beds are folded into an anticline trending E.N.E.-W.S.W., but those in the southern limb of the fold are repeated several times by overthrusting.

The same beds form most of Steep Holme, although here both higher and lower beds may also be present. This, however, still remains to be proved. As in Flat Holm, the chief tectonic feature is an anticlinal fold with its axis running almost in the same direction. Again as on Flat Holm there is considerable overthrusting in the southern limb. The beds examined are very similar to those at Brean Down, both in lithology and fossils.

The very much smaller Denny Island is formed of beds of the Zaphrentis Zone. These have the same north-easterly strike as the limestones of the larger islands but dip consistently N.W. at angles varying from 40° to 50° except where a small anticline only a few feet across, reverses the dip of some of the beds. The southern limb of this insignificant fold is cut off by a minor thrust. It need hardly be pointed out that the similarity of the strike of the limestones on Denny Island with those on Flat Holm and Steep Holme is a matter of coincidence and that the structures are in no way intimately related. Denny Island is part of the Portishead complex while Flat Holm and Steep Holme are continuations of the Mendip folds. On the extreme westerly side of the relatively wide marine platform which surrounds Denny Island at low tide, the Carboniferous beds are overlain by Triassic breccia (the " Dolomitic Conglomerate ").

REVIEWS.

ORE DEPOSITS OF THE WESTERN STATES. LINDGREN VOLUME. By many authors. pp. xxxiv + 797. New York : Published by the American Institute of Mining and Metallurgical Engineers, 1933.

THIS fine volume was unfortunately not sent to the Magazine for review at the time of its publication, but it forms a landmark so important in the literature of economic geology that an apology for the appearance of a notice even at this late date is hardly necessary. As stated in the dedication, it is a tribute of appreciation and admiration of the work of Professor Waldemar Lindgren, on the occasion of his seventieth birthday, from the economic geologists of America. As is usual in such volumes, it consists mainly of a series of monographs by well-known authorities on subjects cognate to the work of the hero of the occasion, and appropriately most of them are directly concerned with the ore-deposits of the Western States.

This, however, gives a very comprehensive scope, and some of the contributions are of sufficiently general character to be of great value as additions to the general theoretical literature of the subject. As an example may be mentioned the third chapter, entitled " Physical-chemical factors in the development of a deep-seated type of ore-deposit ", by Ross, Fenner, Bowen, and Schaller : these names speak for themselves. There is also a chapter entitled " Differentiation and Ore-Deposition, Cordilleran Region of the United States ", by Professor Lindgren himself, which gives in some thirty pages a remarkably clear exposition of his own general theories of ore-formation, which can be applied to most metalliferous regions of the world.

The general line of thought set forth in the chapters on the genesis of primary ores is that the origin is in nearly all cases either directly or indirectly magmatic, and this naturally raises the question of how far the term magmatic should be extended. The general attitude is very well and concisely expressed in the following quotation from Professor Graton's chapter (p. 81) " that extremely important family of ore-deposits which are now universally classed as hydrothermal and generally regarded as of magmatic derivation ". In other words the general view is that hydrothermal processes are really a stage in the cooling of a magma. This point of view disposes of a great deal of unnecessary argument in the past as to whether certain deposits are magmatic or hydrothermal: it is simplest and most logical to regard them as both. It is probable that few workable ores have crystallized directly from a molten silicate magma, but it is impossible to draw a hard and fast line between such a magma and the solutions, in the broadest sense of the word, that escape from it. Any attempt to do so has always broken down.

It is impossible in the space at our disposal to give even a list of the contributors to this volume, much less a synopsis of the contents of their contributions. It must suffice to say that students of ore-deposits, in whatever branch of the subject they are specially interested, even the sedimentary types, will find here something of value written by first-class authorities. It is undoubtedly the most important book on its subject now in existence.

R. H. R.

La Géologie et les Mines des vieilles plateformes. By F. Blondel. pp. 303, with 59 figs. Paris: Société d'Editions Géographiques, Maritimes et Coloniales, 1936.

THE author of this book, a well-known authority on his subject, has set himself the task of discussing, partly from a general point of view, but ultimately with reference to the extensive colonial possessions of France, the relative importance of the mineral deposits of the different structural units of the earth. His first broad distinction is into the ancient platforms, and the geosynclinal areas, while also taking into account hinge-zones and unstable shelves. In the ancient stable blocks he also attempts to discriminate between the crystalline nucleus and the semi-metamorphic series on the one hand, and their cover on the other. The general idea is that the base of the cover is the oldest flat-lying sediment: it is in connection with this that his difficulties begin. Taking, for example, South Africa, Monsieur Blondel in one place begins his cover with the Witwatersrand System, in another place with the base of the Transvaal system, while in still another he insists on the horizontality of the base of the Karroo System. In any case, the base of the Witwatersrand is not a good horizon for this purpose: very few non-African geologists appear to realize how very limited are its surface exposures compared with the size of South Africa.

Space will not allow of a discussion of other debatable points, e.g. the assignment of the Transvaal system to the Silurian, or of the Waterberg to the Devonian, or the supposed flatness of the Dwyka "in the extreme south" (p. 73). Enough has now been said to show the difficulty of the classifications attempted, though it is only fair to say that in later passages the author himself expresses doubt on some of them.

In the discussion of North America one useful point, not always fully appreciated by British geologists, is the great importance of the fold-ranges bordering the Pacific, which are *not* Alpine, but late Jurassic or very early Cretaceous, more likely the former. Also the Burmese–Malayan arc is emphasized as being Mesozoic. M. Blondel is inclined to regard it as Hercynian, which does not seem very satisfactory, as it may be as late as early Cretaceous.

However, in spite of a few occasional incongruities, which as a matter of fact mainly concern the geosynclines and not the continental blocks, the book as a whole is extremely interesting and gives much food for thought, though it must be admitted that the conclusions do not appear to be very definite. The discussion of the distribution of tin ores is very interesting, but too long to summarize here. From a diagrammatic table on p. 265 the following may be extracted as the chief results: the crystalline nucleus is specially rich only in gold and graphite; copper, zinc, and lead being very subordinate. In the semi-metamorphic series copper, gold, cobalt, diamond, iron, manganese, tin, asbestos, chromium, platinum, nickel, and mica are all fairly abundant. In the cover coal, oil, copper, gold, lead, zinc, cobalt, and diamond are important, especially oil, gold, and diamond; but with few exceptions, especially gold, nearly all these products are much more important in the mobile zones of the crust.

R. H. R.

GEOLOGY OF THE TAMPICO REGION, MEXICO. By JOHN M. MUIR. pp. xix + 280, with 40 text-figures (5 as separate sheets), and 15 plates. American Association of Petroleum Geologists, Tulsa; Thomas Murby and Co., London, 1936. Price 19*s*. 6*d*.

IN preparing this authoritative account of the stratigraphy and structure of the oil-fields of southern Tamaulipas and northern Vera Cruz, the author has provided an admirably impartial summary of the published literature, supplemented extensively from the vast bulk of data accumulated by the Mexican oil companies and by his own observations over a period of more than twenty years. His book will long remain the standard authority for its subject, and an indispensable work of reference. It is clearly written and well illustrated with sub-surface maps of the whole of the oil-fields, supplemented by more detailed plans of particular areas. There is also a clear map of the surface-geology of the whole region.

The account of the Jurassic is mainly based on Burckhardt's work. The chapters on the Cretaceous and Tertiary are particularly valuable, since here the author applies his intimate knowledge of the beds in the wells and at outcrop. Both in the Northern Fields, situated on the southward plunge of the Sierra Tamaulipas Anticline, and in the Southern Fields, along the crest of a buried ridge, the producing horizons lie about the middle of the Cretaceous. But while production is governed in the north by fracture belts in massive limestones, in the south it comes from a contemporaneous reef-facies, which in one well reaches the amazing thickness of over 8,000 feet.

Various changes are made in stratigraphical nomenclature in order to eliminate past misconceptions. In the Tertiary the Aragon of Nuttall is placed as a division of the Lower Eocene Chicontepec Group and the Gyuayabal of Cole is assigned to the Middle Eocene Tempoal Formation. The type-locality of Dumble's Alazan is shown to be particularly unsuitable for the purpose, besides including both Upper Eocene (Chapapote of Cole) and Lower Oligocene (for which the name Huasteca Formation is proposed).

The brief account of igneous rocks, which abound, indicates a wide and little-explored field for research. W. Staub is quoted for the existence of a foyaitic region in Tamaulipas and the late H. H. Thomas supplies notes on a number of calc-alkaline intrusives.

Where so much is given it is ungrateful to ask for more, but little is said about structural conditions in the great tectonic depression between the Panuco River and the Southern Fields. A fair number of wells have been drilled between the Tempoal Valley and the sea, and a small scale-map indicating their results would have been of considerable interest.

The book worthily maintains the high standard set by previous publications of its sponsors, and increases the debt of gratitude which geologists in general already owe them.

J. S. T.

THE CARBONIFEROUS LIMESTONE SERIES (AVONIAN) OF THE AVON GORGE. By A. VAUGHAN. Revised with certain additional sections by S. H. REYNOLDS. *Proceedings, Bristol Naturalists' Society*, Fourth Series, Vol. VIII, Part I, for 1935, pp. 29–90, plates 1–15. Price 2*s*. 6*d*. (postage 3*d*.), from the Hon. Secretary, Bristol Naturalists' Society, The Museum and Art Gallery, Bristol 8.

STUDENTS of Lower Carboniferous stratigraphy will welcome the re-issue of this paper, and scores of visiting geologists who have been so courteously conducted over the section by Professor Reynolds will be pleased that he has edited it. The descriptions of brachiopod and coral genera are omitted as being out of date ; otherwise, the original text is reprinted with only those changes necessitated by the construction of Portway and the destruction of the Hotwells Railway Section. Remarks on the lithology and the condition of the outcrops to-day are given in a new section, and changes in zonal and palaeontological nomenclature are shown in new tables, the coral names being revised by Dr. Stanley Smith, and the Brachiopod names by Miss H. Muir-Wood. A new and beautiful series of photographs, lettered to show the extent of the zones, fully illustrates the succession in the Gorge. Altogether the revision is a fitting handbook to this classic section.

D. H.

CORRESPONDENCE.

GEOLOGY OF KAVIRONDO.

SIR,—I am very grateful to Mr. Wayland for drawing your attentions to publications by the Uganda Geological Survey dealing with the geology of Kavirondo (GEOLOGICAL MAGAZINE, July, 1936). But, whilst one may be a great admirer of the Uganda Survey, it would seem to be unreasonable to force mention of their papers. My paper (GEOLOGICAL MAGAZINE, January, 1936) dealt with only a small area near Kakamega, and the preliminary remarks then made still hold good as far as Kakamega is concerned. Mr. Combe's reports deal with an area south-west of Yala which is never considered, in Kenya at any rate, as part of the Kakamega area, and none of the papers mentioned by Mr. Wayland dealt with areas adjacent to that which I was describing.

It would be a controvertible point whether Mr. Wayland's statement that Combe's suggestions for prospecting in northern Maragoli led to the discovery of the Kakamega goldfield. The goldfield was " discovered " by non-official Kenya residents who had not access to the private report lodged with the Secretariat, and in any case, the presence of gold in the Kakamega area had been known for many years before the rise in the price of gold turned people's thoughts to the possibilities of winning it.

WILLIAM PULFREY.

KENYA.
25th October, 1936.

ANNOUNCEMENTS.

The Lord President of the Council has appointed Professor E. B. Bailey, M.C., M.A., D.Sc., F.R.S., Professor of Geology in the University of Glasgow, to be Director of the Geological Survey of Great Britain and Museum of Practical Geology. Professor Bailey served on the staff of the Geological Survey from 1902 until December, 1929, when he resigned from his position of District Geologist on appointment as Professor at Glasgow.

A course of three lectures on " The Subsurface Structure and the Sediments in the Great Basin of North-Western Europe " will be given by Dr. W. A. J. M. van Waterschoot van der Gracht, at King's College, London, on 1st, 2nd, and 3rd March, 1937, at 5.30 p.m.

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ORIGINAL ARTICLES.

On some Ordovician Fossils from Northern Argentina.[1]

By H. J. HARRINGTON, Buenos Aires.

(PLATES V–VII.)

I. INTRODUCTION.

THE North Argentine fossils described in this paper were collected by Professor J. Keidel during 1919, 1932, and 1934, from several stratigraphical levels in the Quebrada del Toro (Province of Salta), and in 1916 from a single horizon further north in the Quebrada de Chalala near the Quebrada de Purmamarca (Province of Jujuy).

The Ordovician rocks exposed in the mountain range which forms the divide between the Quebrada del Toro and the Quebrada de Incamayo exceed 3,000 metres in thickness,[2] and can be traced throughout the pre-Puna region. The sequence comprises four groups which Professor Keidel has named, in descending order, the Incamayo, Parcha, Saladillo, and Cardonal groups.

The lower portion of the Cardonal group is formed by apparently unfossiliferous clay-slaty rocks, which are in part similar to varves. The upper part is formed by quartzites, quartzitic sandstones, and the "*Bilobites* sandstone". Most of these beds are devoid of fossils, but the topmost layers have provided two small faunules. The older of the two, characterized by the presence of the genus *Kainella*, has yielded: *Kainella conica* Kobayashi, *Andesaspis argentinensis* Kobayashi, *Eoorthis* (?) *putilliformis* Kobayashi, *Lingulella* (?) sp. indet.

The fossils described by Kobayashi (1935*a*)[3] from "Prairie Catamarca" in Northern Argentina mostly came from this zone.

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[1] This paper forms part of a thesis presented in 1936 to the University of Oxford for the degree of D.Phil.

[2] These notes on the Ordovician series of Northern Argentina are a brief and incomplete summary of Professor Keidel's as yet unpublished investigations, which he has kindly permitted me to mention. Professor Keidel is preparing an extensive paper on this subject, which will be published elsewhere.

[3] See list of references at the end of this paper.

They were collected in 1907 by Professor Keidel from the lower part of the Ordovician exposed in the Quebrada Colorada near Iruya, Salta.[1] These fossils were found at different levels, but it seems that the original labels have been lost and all the species were described as coming from a single stratigraphical horizon. Most of them, however, seem to belong to the *Kainella* zone of the Cardonal group, but *Oxydiscus keideli* is probably a much younger form.

Immediately above this horizon there is another fossiliferous level, from which the following have been collected : *Leiostegium douglasi* sp. nov., *Keidelaspis saltensis* gen. et sp. nov., *Eoorthis saltensis* (Kayser) Walcott, *Eoorthis* sp. indet., *Obolus* (?) *lampazarensis* sp. nov., *Lingulella* (?) spp. indet. a et b, *Hyolithus* sp. indet.

Hoek has recorded *Eoorthis* ("*Orthis*") *saltensis* and pygidia of *Megalaspis* cf. *planilimbata* from Aguas Calientes (Quebrada de Reyes) from beds which Professor Keidel considers to be those of the *Leiostegium* zone.[1] Not improbably these pygidia, which have not been figured, belong to some species of *Leiostegium.*

Between the Cardonal beds and the Saladillo group there is an important stratigraphical hiatus which is especially evident on the side of the Quebrada del Toro, between the Saladillo and the Cerro Gólgota. The Saladillo group is characterized by the presence, in its lower part, of several layers of marine-glacial deposits enclosing many well-striated boulders and pebbles. Many of these pebbles, some of them fossiliferous, come from the underlying Cardonal group.

From arenaceous-calcareous beds of the marine-glacial series the following fossils were collected : *Oxydiscus keideli* Kobayashi, *Eoorthis bifurcata* sp. nov., *Eoorthis* sp. indet., *Endoceras* spp. indet. a et b, Gastropoda gen. et sp. indet.

The Parcha group comprises quartzites, quartzitic slates, and similar rocks. Fossils are very scarce, but in the lower beds of this group have been found *Basilicoides taurinus* gen. et sp. nov. and *Endoceras* sp. indet.

The uppermost or Incamayo group of the Ordovician is formed by dark clay-slates and a few layers of sandstone with very infrequent fossils ; some indeterminable inarticulate brachiopods only have been collected.

The Proterozoic beds of the western flank of the Quebrada de Incamayo are thrust over the Ordovician Incamayo group. On both sides of the lateral valley of Abra Grande near Incahuasi, Mesozoic limestones are seen emerging from beneath the thrust-plane and unconformably overlying the beds of the Incamayo group.

From Mts. Gólgota and Incamayo southwards the Ordovician and Cambrian strata forming the floor of the Quebrada del Toro are completely crushed between two huge masses of Proterozoic beds.

The Ordovician series of the pre-Puna lies on a series of bright-coloured sediments of Cambrian age, but the Cardonal group is sometimes transgressive on to the Proterozoic strata. The Cambrian series is characterized by the presence of "*Scolithus*" in its middle part, and from these beds probably come the *Conocephalites* cf. *striatus* Emm. described by Hoek from the Cuesta de Escayache in Bolivia and *Crepicephalus* ("*Olenus*") *argentinus* (Kayser) from Tilcuya, to the north of the Argentine-Bolivian boundary.

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[1] Letter of 10th March, 1936.

The Ordovician beds of the Quebrada de Purmamarca are found, some 4 km. to the west of Purmamarca, underlying the limestones and other Mesozoic sediments and separated by a thrust-plane from the underlying Proterozoic strata. Here, in the Quebradas de Chalala and Coquena, two different fossiliferous levels have been found. The faunule of the lower horizon, recently discovered by Professor Keidel and Mr. de Ferraris, will be dealt with in a future paper. The fossils described in this paper, collected in the Quebrada de Chalala, belong to the upper horizon and include: *Asaphellus jujuanus* sp. nov., *Protopliomerops primigenus* (Angelin) Kobayashi, *Agnostus* sp. indet., *Eoorthis christianiae* (Kjerulf) Walcott, *Obolus* (*Bröggeria*) cf. *salteri* (Holl) Walcott, *Lingulella* (?) sp. indet., *Hyolithus* (*Orthotheca*) *multistriatus* sp. nov., Cystoidea gen. et sp. indet.

This fauna shows affinities with part of the British Tremadocian, the Euloma-Niobe fauna of the Baltic, and the Tomkolian of South-Eastern Asia.

Protopliomerops primigenus is known from the *Apatokephalus* zone of Scandinavia and the B_1 stage of the Baltic provinces of Russia. *Eoorthis christianiae* has been found in the *Apatokephalus*, *Shumardia*, and *Acerocare* zones of Scandinavia. In the *Shumardia* zone it is sometimes associated with *Obolus* (*Bröggeria*) *salteri*.

Asaphellus jujuanus sp. nov. is a form allied to *A. tomkolensis* from the Tomkolian (Tremadocian) of South Chosen and the minute *Agnostus* sp. indet. from Purmamarca is also similar to a Tomkolian species.

This very characteristic association thus shows a typical Atlantic facies of the Basal Ordovician.

The fossils found in the *Kainella* and *Leiostegium* zones of the Ordovician series of the Quebrada del Toro belong, on the contrary, to the Pacific province.

Kainella conica and *Andesaspis argentinensis* are the characteristic fossils in the *Kainella* zone, and these species have recently been discussed by Kobayashi (1935*a*). In his opinion they represent, together with the other fossils from the Quebrada Colorada, the late Ozarkian of Western North America.

Leiostegium douglasi sp. nov., which characterizes the *Leiostegium* zone, is closely allied to *L. manitouensis* from the Manitou Limestone of Colorado and the Chushina Formation of British Columbia (Upper Ozarkian). The genus occurs elsewhere in the upper zones of the Ozarkian and has been found both in the *Kainella* zone (Billings Butte fauna of the Robson Peak area) and in the *Ozarkispira* zone

(*Ozamia* zone of the Clearwater Canyon section). According to Kobayashi (1934*b*, p. 539), "in an unpublished correlation chart Ulrich places the *Leiostegium* zone in the uppermost part of the Ozarkian. In a certain zone, therefore, *Leiostegium* is one of the characteristic American fossils."

Finally, *Eoorthis saltensis* from the *Leiostegium* zone and *E.* (?) *putilliformis* from the *Kainella* zone are forms closely allied to *E. putillus* from the Chushina Formation of the Robson Peak area of British Columbia (Billings Butte fauna).

The few fossils collected in the arenaceous-calcareous beds of the marine-glacial deposits of the Saladillo group are not characteristic enough to warrant an exact determination of the age.

The age of the lower part of the Parcha group may be provisionally considered as Llandeilian. The only determinable remains found in these beds are those of *Basilicoides taurinus* gen. et sp. nov. This genus seems to be closely allied to *Basilicus* and *Ogygitoides*, both of which are thought to be Llandeilian genera.

If this determination of the age of the Parcha group is correct, the Saladillo group, separated from the Cardonal beds by a disconformity, could be of Upper Beekmantown age. The presence of such an advanced Bellerophontid as *Oxydiscus keideli* would seem to corroborate this idea.

It is interesting to point out that until now the *Bilobites* sandstone of the Cardonal group has been considered as the equivalent of the "grés armoricain", following Haug's opinion (1927, p. 644), and thus of Arenig age.

The stratigraphical relationship between the *Asaphellus* zone of the Quebrada de Chalala, the *Kainella-Leiostegium* zones of the Quebrada del Toro and the *Parabolinella* zone of the Quebrada de Humahuaca is not known (Kobayashi, 1936). It seems that the *Kainella* and *Leiostegium* zones do not exist, as fossiliferous beds, to the east of the Quebrada de Humahuaca.

According to the views held by Raymond and other geologists the Tremadocian of Europe is separated from the underlying Cambrian by a stratigraphical hiatus which, in the west of the North American continent, would be represented by the Upper Ozarkian. If these views are correct the *Asaphellus* zone of Purmamarca would be younger than the *Leiostegium* zone of the Cardonal group and older than Saladillo beds. If we remember that between the *Leiostegium* zone and the lower beds of the Saladillo group there is a considerable stratigraphical break, the Purmamarca beds could be considered as having been deposited during this interval of time.

There is, however, an alternative hypothesis which has been extensively discussed by Kobayashi (1933*a*). According to this view, the European Tremadocian is the Atlantic representative of the North American "Late Ozarkian". They are considered to be contemporaneous, the former characterized by an "Atlantic" fauna of the European Meridional Province and the latter by a

"Pacific" fauna of the American Septentrional Province. Thus, in Kobayashi's opinion, the "Late Ozarkian" is more a palaeogeographical than a chronological term.

In accordance with this second view the *Asaphellus* zone of Purmamarca could be correlated with the Tomkolian of South-Eastern Asia, while the Late Ozarkian beds of the Quebrada del Toro could be the equivalent of the Wanwanian of North-Eastern Asia.

No evidence in one way or the other is afforded by the study of the Basal Ordovician fossils described in this paper. The question can only be answered by a detailed study of the field relationship between the different fossiliferous zones.

The following stratigraphical scheme of the Lower Palaeozoic series of the pre-Puna has been kindly prepared by Professor Keidel at my request.

Ordovician	Incamayo group	Unfossiliferous beds.
	Parcha group	Upper beds, unfossiliferous. *Basilicoides* zone.
	Saladillo group	Fossiliferous beds of the marine-glacial deposits.
		Disconformity
	Cardonal group	*Leiostegium* zone. *Kainella* zone. Quartzitic sandstones, etc. Slaty sandstones, etc.
Cambrian		Upper quartzitic sandstones. "*Scolithus*" sandstones. Lower quartzitic sandstones.
		Unconformity
Proterozoic beds with granitic intrusions, folded during pre-Cambrian times.		

DESCRIPTION OF THE FOSSILS.[1]

CYSTOIDEA.

Genus et species indet.

Plate V, Fig. 8.

The Cystid remains consist of a single plate and numerous detached stem-joints.

The plate is roundedly hexagonal in outline, somewhat elevated in the centre, and measuring 6 mm. in diameter. Six radial ribs diverge from a central button, and in each interspace between the ribs there are two or three V-shaped ridges (hydrospires).

The stem-joints are small, flat, ring-shaped, with an average diameter of about 1·5 mm.

The calycal plate just described closely resembles the specimens figured by Kobayashi from the *Eoorthis* zone of Tomkol (Upper Cambrian of South Chosen).[1] These specimens, however, show 5–6 hydrospires instead of 2–3.

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[1] All the fossils described in this paper are in the collections of the Dirección de Minas y Geología, Buenos Aires.

Similar plates have been described by Poulsen from the Upper Ozarkian of Cass Fjord, Greenland,[2] but they differ from our specimen in having tuberculate radial ribs.

Locality and Horizon.—Quebrada de Chalala. *Asaphellus* zone, Tremadocian.

BRACHIOPODA.

Genus *Obolus* Eichwald, 1829.

Obolus (?) *lampazarensis* sp. nov.

Plate VI, Fig. 10.

Valves subequal, slightly and evenly convex, almost perfectly circular in outline. The ventral valve slightly more acuminate. Average length and width of the dorsal valve, 7·5 to 8 mm.

Surface marked by fine concentric striae and lines of growth, and also by fine radiating striae and lines.

Interior of the dorsal valve known from two imperfect specimens which only show the central and anterior regions of the shell. There is a low median septum that extends to less than the middle distance between the anterior and posterior margins. At about its middle length there is a pair of small scars (central muscle scars). The very small anterior lateral muscle scars are seen close to the septum, near its anterior end. From the anterior region of the septum two shallow vascular markings extend forwards and outwards towards the antero-lateral margins. These gently curving, horn-like grooves reach to about the middle distance between the end of the septum and the margins.

Interior of the ventral valve unknown.

Observations.—The central muscle scars are seen at the anterior end and inner side of a pair of converging markings, which probably correspond to the "horn-like" grooves which in the typical *Obulus* arise from the sinus at the posterior end of the septum.

In some species of *Obolus*, *O. matinalis* (Hall) Walcott, for instance, the "horn-like" grooves seem to be absent.[3] The presence of a shallow sinus at the posterior end of the septum seems to be the only distinguishing character from such species of *Lingulella* as *L. similis* (Walcott).[4]

In *Obolus selwyni* (Matthew) Walcott, the "horn-like" grooves do not originate at the posterior median sinus, which seems to be absent in this species. On the other hand, in such forms as *Lingulella ampla* (Owen) Walcott, it would seem that the central muscle scars are placed on the inner side of a pair of "horn-like" grooves, much as in the typical *Obolus*.[1]

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[1] Kobayashi, T., 1935*b*, pl. ii, fig. 17–18, and pl. iii, fig. 24.
[2] Poulsen, Ch., 1927, pl. xvii, figs. 38–9, and p. 282.
[3] Walcott, C. D., 1912, pl. viii, fig. 1*b*.
[4] Walcott, C. D., 1912, pl. xxi, fig. 2*a*.

Although the evidence afforded by the internal characters of the dorsal valve is thus not wholly conclusive, the almost perfectly circular outline of the shell seems to point to *Obolus* rather than to *Lingulella*.

Locality and Horizon.—Quebrada de Lampazar, Salta. *Leiostegium* zone, Upper Ozarkian.

Subgenus *Bröggeria* Walcott, 1902.

Obolus (*Bröggeria*) cf. *salteri* (Holl) Walcott.

Plate V, Fig. 4.

Shell subtriangular in outline, of moderate size, thin, and shiny. Length 7·5 to 8·5 mm.; width 8 to 9 mm.

Surface covered with crowded concentric striae and lines of growth, somewhat wavy and irregular. No radial striae observable on the outer layers of the shell. The inner layers apparently show radial lines, but this character is somewhat doubtful.

Inner surface of the shell marked by very small pits irregularly distributed.

Observations.—Although the internal characters of the shells described above are not known, the shells seem to be indistinguishable from *Obolus* (*Bröggeria*) *salteri* (Holl) Walcott as regards their general outline and external characters.

Our shells can be compared with some of the specimens figured by Walcott[2] and Matley[3]. They are perhaps slightly more triangular than the more triangular specimens figured by Walcott, but this character is only a minor difference.

Our specimens can also be compared with *Obolus feistmanteli* (Barrande) Walcott from Bohemia,[4] and by their triangular outline with *Obolus triangularis* Mickwitz from the *Obolus* sandstone of the Baltic[5] and *O. trigonalis* Kobayashi from the Upper Cambrian of Liaotung.[6]

Locality and Horizon.—Quebrada de Chalala. *Asaphellus* zone, Tremadocian.

Genus *Lingulella* Salter, 1866.

Lingulella (?) sp. a indet.

Plate V, Fig. 6.

There is a single ventral valve in the collection of Quebrada de Purmamarca, which probably corresponds to a species of *Lingulella* Salter.

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[1] Walcott, C. D., 1912, pl. xxxvi, figs. 1*e* and 1*d*, and pl. xxviii, fig. 1*g*.
[2] Walcott, C. D., 1912, pl. xiii, figs. 1*i* and 1*n*.
[3] Matley, C. A., 1902, p. 138, fig. 4.
[4] Walcott, C. D., 1912, pl. xii, fig. 1.
[5] Mickwitz, A., 1896, pl. ii, fig. 7–9.
[6] Kobayashi, T., 1933*b*, pl. ix, fig. 12.

It is acuminate-ovate in outline with an area of moderate size. It measures 12·5 mm. in length and 12 mm. in width.

The surface is covered by concentric lines of growth and by fine radial striae. Nothing is known of the internal structure.

The valve is rather similar in size and shape to some specimens of *Lingulella* (*Leptembolon*) *lingulaeformis* (Mickwitz) Walcott, as figured by Walcott from the *Obolus* Sandstone of Esthonia.[1]

Locality and Horizon.—Quebrada de Chalala, Jujuy. *Asaphellus* zone, Tremadocian.

Lingulella (?) sp. b indet.

Shell elongate-ovate, strongly acuminate, of moderate size, smooth. A single specimen measuring 8·5 mm. in length and 4 mm. in width.

In general outline it resembles *Lingula lineata* Hoek from the Ordovician of Bolivia,[2] but is much smaller in size and perfectly smooth. This last character may be due to the very coarse matrix in which it is found.

Locality and Horizon.—Pueblo Viejo, Quebrada del Toro, Salta. *Leiostegium* zone, Upper Ozarkian.

Lingulella (?) sp. c indet.

Plate VII, Fig. 4.

A single valve (apparently dorsal), preserved in a very coarse quartzitic sandstone.

Large size, roundly ovate in outline, moderately convex both longitudinally and transversely. It measures 13 mm. in length and 10 mm. in width.

Surface marked by concentric lines, visible only near the margins. The central part of the shell has been eroded and the ornamentation has not been preserved.

By its general outline this valve resembles *Lingulella ninus* Walcott and *L. miltoni* Walcott from the Chushina formation of British Columbia,[3] but these two forms are much smaller than the present one.

Locality and Horizon.—Pueblo Viejo, Quebrada del Toro, Salta. *Leiostegium* zone, Upper Ozarkian.

Genus *Eoorthis* Walcott, 1908.

Eoorthis saltensis (Kayser) Walcott.

Plate VII, Fig. 5.

Shell subcircular in outline or somewhat transversely elongate. Hinge-line straight, usually about three-quarters of the maximum width of the shell, which is measured at the middle distance between the hinge-line and the anterior margin. The ventral valve measures, on the average, 9·5 mm. in length and 10 mm. in width.

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[1] Walcott, C. D., 1912, pl. xiv, fig 5*b*.

[2] Hoek, H., and Steinmann, G., 1912, pl. viii, fig. 1.

[3] Walcott, C. D., 1924, pl. 108, fig. 16, and pl. 122, fig. 4.

Ventral valve moderately arched, raised along the middle line into a distinct carina which is, however, rather faint in some specimens or even almost absent. Beak small, pointed, slightly arched, and raised over the cardinal area.

Dorsal valve flatter than the ventral one, and evenly convex. A shallow sinus, very narrow at the umbo, rapidly increases in width towards the anterior margin, where it is very broad. Beak small, not raised over the area.

Entire surface of both valves covered by numerous ribs, which increase in number by interpolations. The ribs are disposed, especially on the mesial region of the valves, into more or less distinct bundles or fascicules. The main ribs, originating at the beak, are stronger than the intercalated secondary ones. The lateral ribs are bent outwards, the central ones straight.

Internal structure unknown.

Observations.—Our shells seem to be indistinguishable from Kayser's description of "*Orthis*" *saltensis* from Tilcuya, Salta.[1] Kayser's figures, however, fail to reproduce the fasciculated character of the ribs described in the text, as well as the carinated appearance of the ventral valve.

It seems to me difficult to distinguish *E. saltensis* from *Eoorthis putillus* Walcott from the Chushina and Mons formations of British Columbia.[2] They are probably closely related species, if not simple varieties of one and the same species. The only important difference seems to be one of size, *E. saltensis* being, on the whole, somewhat larger than *E. putillus*. *Eoorthis* (?) *putilliformis* Kobayashi from the Basal Ordovician of the Quebrada Colorada near Iruya, Salta,[3] is another form closely allied to *E. saltensis*.

Some small shells from Pueblo Viejo (Quebrada del Toro) are probably a variety of *E. saltensis*. They resemble in size and general outline the specimens figured by Walcott as *E. putillus* var. *laeviuscula* Walcott.[4]

Locality and Horizon.—Quebrada de Lampazar, Salta. *Leiostegium* zone, Upper Ozarkian.

Eoorthis christianiae (Kjerulf) Walcott.

Plate V, Figs. 11–13.

Shell subquadrate. Hinge-line straight, slightly shorter than the maximum width which is measured at the middle distance between the hinge-line and the anterior margin. Cardinal extremities rounded.

Ventral valve moderately convex. Beak pointed, small, slightly raised over the area, but not incurved. No mesial fold.

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[1] Kayser, E., 1878, pl. i, fig. 16, and p. 8.

[2] Walcott, C. D., 1924, pl. 114, figs. 6–7, and pl. 115, fig. 9.

[3] Kobayashi, T., 1935*a*, pl. xi, figs. 21–24.

[4] Walcott, C. D., 1924, pl. 115, fig. 1.

Dorsal valve flatter than the ventral one. Beak small, not raised over the area. Mesial sinus usually present, sometimes strongly marked, narrow at the umbo but broadening rapidly towards the anterior margin.

Entire surface of both valves covered by numerous ribs. The ribs are not arranged in bundles and they increase in number both by interpolation and bifurcation. The bifurcations are only seen in well-preserved specimens, especially good casts of the outer surface of the shell. When the state of preservation is not very good the bifurcations resemble intercalations. Lateral ribs gently bent outwards. Concentric lines of growth are seen in some specimens, where they are usually few, spaced, and well marked.

Internal structure unknown.

Dimensions.	*mm.*	*mm.*	*mm.*	*mm.*
Length of ventral valve	10	—	—	—
Length of dorsal valve	—	8	9	7
Width . . .	12·5	10·5	11	8

Observations.—These shells seem to be indistinguishable from *Eoorthis christianiae* (Kjerulf) from the *Apatokephalus*, *Shumardia*, and *Acerocare* zones of Scandinavia.[1] They agree with that species in the bifurcating character of some of the ribs, as well as in size and general outline. The hinge-line of our specimens seems, however, to be slightly shorter than in *E. christianiae*, recalling the type of *E. daumus* Walcott.

Our shells are distinguished from *E. desmopleura* Walcott, which they otherwise resemble, by the non-fasciculated character of the ribs and by their bifurcations.

From *Eoorthis* (?) *saishoensis* Kobayashi from the Lower Ordovician of South Chosen, they differ in being of rather larger size and because in this species the ribs increase in number only by bifurcations.[2] Kobayashi's species is, however, closely related to *E. christianiae*.

Locality and Horizon.—Quebrada de Chalala, Jujuy. *Asaphellus* zone, Tremadocian.

Eoorthis (?) *putilliformis* Kobayashi.

Plate VI, Figs. 8, 9.

Shell of medium size, rounded subquadrate in outline. Both valves convex, the ventral valve more strongly so than the dorsal. Hinge-line straight, slightly shorter than the maximum width of the shell.

Ventral valve without mesial fold or raised carina. Beak slightly raised over the area.

Dorsal valve with a shallow, ill-defined mesial sinus which is distinct only near the umbo. Beak small, not raised over the area.

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[1] Walcott, C. D., 1912, pl. xcv, figs. 1 and 1*f*.

[2] Kobayashi, T., 1934*b*, pl. iii, figs. 15–18.

Surface entirely covered by numerous ribs which increase in number by intercalation.

Dimensions.	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
Length of ventral valve	9	14	11·5	—	—
Length of dorsal valve	—	—	—	6·5	8·5
Width . . .	10·5	14	12	7·8	10·0

Observations.—These shells closely resemble the figures and description of *Eoorthis* (?) *putilliformis* Kobayashi from the Basal Ordovician of Quebrada Colorada, near Iruya, Salta.[1] They are distinguished from *E. saltensis* and *E. putillus* by the lack of carina or raised median bundle of ribs on the ventral valve of these species.

Locality and Horizon.—Angostura de Parcha, Quebrada de Tucamayo, Salta. *Kainella* zone, Upper Ozarkian.

Eoorthis bifurcata sp. nov.

Plate VII, Fig. 7.

Shell somewhat transversely elongate. Both valves moderately convex. Hinge-line straight, less than the maximum width, which is measured at the centre of the valves.

Ventral valve evenly convex, without mesial fold.

Dorsal valve with a shallow, ill-defined, mesial sinus, which in some specimens is very inconspicuous. Beak small, pointed.

Surface of both valves covered by ribs which increase in number both by interpolation and bifurcation. There are four ribs in the space of 1 mm. at the anterior margin. Some specimens show a few concentric lines of growth.

Internal structure unknown.

A ventral valve measures 10·5 mm. in length and about 14 mm. in width, while a dorsal valve is 6·5 mm. long and 8 mm. wide.

Observations.—These shells belong to the group of *Eoorthis christianiae*, as is shown by the bifurcating character of some of the ribs. They differ from the Scandinavian species in having a smaller number of ribs. Furthermore, the main ribs of *Eoorthis bifurcata* sp. nov. are much stronger than the others, rounded and raised over the surface of the shell. The bifurcations are not so numerous as in *E. christianiae* and the main ribs dichotomize unequally. The secondary riblets branching off from them are more slender than, and sunk between, the main ribs. In *E. christianiae* the primary ribs are usually split near the anterior margin of the valves into two or even three equally strong ribs.

Locality and Horizon.—Outcrop to the north of the path between the Quebrada de Lampazar and the Quebrada de Parcha, Salta. Arenaceous-calcareous beds of the marine-glacial series. Upper Beekmantown ?

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[1] Kobayashi, T., 1935*a*, pl. xi, figs. 21–24, and p. 62.

GASTROPODA.

BELLEROPHONTACEA.

Genus *Oxydiscus* Koken, 1889.

Oxydiscus keideli Kobayashi.

Plate VII, Fig. 6.

A single imperfect specimen from the Quebrada del Toro seems to be identical with *Oxydiscus keideli* Kobayashi from the Quebrada Colorada, Salta.

Only the body whorl is well preserved, the central part of the umbilicus being obscured by the matrix. It is subcordiform in cross-section, and has a steep slope on the umbilical side.

The surface ornamentation consists of numerous ridges which curve back from the ventral to the dorsal side, and show a slight convexity towards the aperture. Our specimen does not show the weak lines subparallel to the keel, which Kobayashi describes in the text.[1] These lines are, however, not apparent in his figures of the holotype.[2] The specimen in hand also agrees with *O. keideli* in size, having about the same measurements as the holotype.

Locality and Horizon.—Outcrop to the north of the path between the Quebrada de Lampazar and the Quebrada de Parcha, Salta. Arenaceous-calcareous beds of the marine-glacial series. Upper Beekmantown ?

PTEROPODA.

Genus *Hyolithus* Eichwald 1840.

Hyolithus sp. indet.

Plate VI, Fig. 14.

Shell straight, tapering at about 1 in 6 or 7. Cross-section subtriangular. Ventral face convex, more or less roundly angulated. Dorsal face gently convex with subacute margins. Mouth with dorsal lip strongly arched. Shell smooth. The largest specimen measures 4 mm. in width at the aperture and more than 17 mm. in length.

Observations.—The smooth character of the shell is somewhat doubtful as the very coarse sandstone in which the fossils are found would not have preserved any fine lines or striae.

Our specimens resemble *Hyolithus* sp. from Tilcuya figured by Kayser,[3] but this species has a more convex ventral face and tapers at about 1 in 5. They also resemble *H. cybele* Walcott from the Middle Cambrian of China,[4] but this form attains a larger size and tapers at about 1 in 4.

Locality and Horizon.—Pueblo Viejo, Quebrada del Toro, Salta. *Leiostegium* zone, Upper Ozarkian.

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[1] Kobayashi, T., 1935*a*, p. 63.

[2] Kobayashi, T., 1935*a*, pl. xi, fig. 19–20.

[3] Kayser, E., 1878, pl. i, fig. 18.

[4] Walcott, C. D., 1913, pl. 5, fig. 16.

Subgenus *Orthotheca* Novák.

Hyolithus (*Orthotheca*) *multistriatus* sp. nov.

Plate V, Fig. 1.

Shell straight, slowly tapering at about 1 in 9 or 10. Ventral face unknown. Dorsal face flat, straight at its anterior end and truncated.

Dorsal face ornamented with very fine, wavy longitudinal striae of equal size and equidistant. There are about twenty striae in the space of 1 mm. A few widely spaced faint transverse lines are barely visible in one specimen. The largest specimen measures 4·6 mm. at the aperture; its length is not known, but judging by the slow tapering of the shell it probably was 30 mm. or even more.

Observations.—Although this species is known only by two fragmentary dorsal faces, the peculiar ornamentation makes it easy to distinguish it from other Orthothecae. The "wavy" character of the longitudinal striae may be compared with that shown by the transverse striae of *Conularia bohemica* Barrande.[1]

Locality and Horizon.—Quebrada de Chalala, Jujuy. *Asaphellus* zone, Tremadocian.

Genus et species indet.

A few internal casts of gastropods which seem to belong to the family Pleurotomaridae have been collected from the marine-glacial beds of the Saladillo group.

Some of the remains resemble those of the genus *Hormotoma* Salter, showing the lines of growth as figured by Ulrich and Scofield.[2] They are, however, too fragmentary for generic identification.

CEPHALOPODA.

Fam. *Endoceratidae* Hyatt.

Plate VII, Figs. 2, 3, 11.

Several orthoceracones were collected from the Saladillo group and the *Basilicoides* zone of the Parcha group. They are, without exception, internal casts of the conch.

The specimen figured in Plate VII, Fig. 2, from the marine-glacial deposits of the Saladillo group (outcrop to the north of the path between the Quebrada de Lampazar and Parcha) probably belongs to the genus *Endoceras* Hall. It is an internal cast showing about ten camerae. The conch is laterally compressed by secondary deformation and the original outline is unknown. Siphuncle of moderate width, marginal, in contact with the wall of the conch.

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[1] Barrande, J., 1867, pl. i, fig. 1.

[2] Ulrich, E. O., and Schofield, W. H., 1897, pl. lxx.

Funnels extend apicad to the level of the septum next to that from which they originated. Characters of the endosiphuncle unknown. Camerae not crowded ; there are five septa in the space of 10 mm. Surface of the cast of the siphuncle showing the characteristic oblique shallow grooves and ridges caused by the overlapping of the posterior portion of the funnels.

The specimen figured in Plate VII, Fig. 3, from the same locality closely resembles the above mentioned one, but is distinguished from it by the much more crowded camerae—there are seven septa in the space of 5 mm.—the narrower siphuncle and longer siphunclar funnels. Probably it can also be considered as *Endoceras* sp., although the crowded character of the camerae is more typical of the Ellesmereoceratidae.

The specimen shown on Plate VII, Fig. 11, from the *Basilicoides*-zone of the Parcha group (outcrop of the western flank of the dividing range between the Quebrada del Toro and the Quebrada de Incamayo), closely resembles the *Endoceras* sp. figured by Douglas from the Llanvirnian graptolite shale of the Yuscamayo, Perú.[1] Both specimens show part of the body chamber, and show eight septa in the space of 10 mm. and in both the trace of the septa are bent apicad at the siphonal wall. In the Peruvian specimen traces of the siphuncular funnels are observed, while in the present one they have not been preserved.

TRILOBITA.

Genus *Agnostus* Brongniart, 1822.

Agnostus sp. indet.

Plate V, Fig. 7.

Cephalon as long as broad, with a semi-parabolic outline. Glabella consisting of a small subtriangular anterior lobe and a subquadrangular posterior one. Test smooth. Apparently no brim is present, though this character is somewhat doubtful.

The only specimen measures 1·5 mm. in length by 1·5 mm. in width. The glabella is 1 mm. long and slightly less than 1 mm. wide. Anterior lobe about 0·3 mm. long.

Observations.—This isolated cephalon resembles *Agnostus* (*Ptychagnostus* ?) *radiarus* Kobayashi from the *Asaphellus* zone of Makkol (Tomkolian of South Chosen), but that species is rather larger than our specimen, as it measures 3 mm. in length.[2]

Locality and Horizon.—Quebrada de Chalala, Jujuy. *Asaphellus* zone, Tremadocian.

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[1] Douglas, J. A., 1933, pl. xxix, fig. 2. In the explanation of plate xxix the specimens of figs. 1 and 2 appear as *Engonoceras* sp. This is obviously a clerical error for *Endoceras* sp.

[2] Kobayashi, T., 1934*b*, pl. iii, fig. 1.

Genus *Andesaspis* Kobayashi, 1935.

Andesaspis argentinensis Kobayashi.

Plate VII, Figs. 8–10.

Andesaspis argentinensis Kobayashi described from the Basal Ordovician of Quebrada Colorada, near Iruya, Salta, is represented in this collection by a few cranidia and free cheeks, some of them fairly well preserved. No pygidia have been found.

The specimens agree with the description and figures given by Kobayashi.[1] The average length of the cranidium is 5 mm., while the glabella is usually some 4·5 mm. long and 3·5 mm. wide at the base. A large free cheek measuring 12 mm. in length probably belongs to the same species.

Locality and Horizon.—Angostura de Parcha (Quebrada de Incamayo), Salta. *Kainella* zone, Upper Ozarkian.

Genus *Keidelaspis* nov.[2]

Diagnosis.—Cranidium subquadrate. Glabella subquadrate, rounded in front. Dorsal furrows subparallel; glabellar furrows obsolete. Occipital furrow well marked. Frontal margin very narrow; frontal limb very wide. Preglabellar area subquadrate in outline. Fixed cheeks narrow. Eyes small, slightly nearer to the anterior than to the posterior margin. Ocular ridge absent. Anterior branches of the facial sutures subparallel from the eyes to the margin, then intramarginal to the mid-line.

Pygidium small, entire, with few axial segments and faint lateral furrows.

Genotype.—Keidelaspis saltensis gen. et sp. nov.

Keidelaspis saltensis gen. et sp. nov.

Plate VI, Figs. 5–7.

Cranidium feebly convex. Glabella subquadrate, evenly rounded or somewhat truncato-rounded in front. Dorsal furrows well marked; glabella slightly convex both longitudinally and transversely, somewhat elevated over the fixed cheeks. Glabellar furrows obsolete or, in some specimens, as very faint and ill-defined indications. Occipital furrow and ring well developed.

Frontal margin very narrow, about half the width of the occipital ring. Frontal limb wide, in some specimens about five times as wide as the frontal margin.

Fixed cheeks narrow, with postero-lateral limbs. Eyes small, placed near the anterior end of the glabella. Ocular ridge absent. Anterior branches of the facial sutures parallel from the eyes to the margin, then, cutting the margin very obliquely, converge towards the middle line, meeting on the upper surface of the body.

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[1] Kobayashi, T., 1935*a*, pl. xi, figs. 1–2, and p. 67.

[2] The name *Keidelaspis* is proposed in honour of Dr. J. Keidel.

Associated pygidium small, entire, and segmented. The width of the axial lobe equals one-third of the total width. Axial lobe bearing four well-defined segments and ending in a small unsegmented, rounded, and elevated stump. Lateral furrows faint. Margin wide, rather ill-defined, without a marginal furrow, slightly convex.

Dimensions.	*mm.*	*mm.*	*mm.*
Length of the cranidium .	10·0	8·5	—
Width of the cranidium .	16	—	—
Length of the glabella .	7·4	6·3	—
Width of glabella at base	6·5	5	—
Width of anterior margin	0·4	0·3	—
Width of frontal limb .	1·8	1·8	—
Width of neck ring .	1·0	0·9	—
Length of pygidium .	—	—	3·5
Width of pygidium .	—	—	7
Width of axial lobe .	—	—	2·4

Observations.—Although *Keidelaspis* resembles *Angelina* Salter in the major features of the cranidium, it would be unsafe to draw from this resemblance any conclusions regarding the relationship of *Keidelaspis* with the true Olenidae.

Keidelaspis may be compared with *Liostracus* Angelin and *Andesaspis* Kobayashi. From the first named genus it differs in the character of the anterior branches of the facial sutures, which are not intramarginal. From *Andesaspis* it is easily distinguished, for that has a narrow frontal limb and serrated pygidium.

It is also similar to the two species of "*Liostracus*" described by Kayser from Iruya, Salta.[1] The pygidia figured by Kayser have, however, a well-defined margin and deeply marked lateral furrows. Furthermore, the cranidia are much more convex, the eyes are more anteriorly placed, and it seems that the facial sutures are not intramarginal.

Kobayashi has already pointed out that Kayser's species cannot be referred to *Liostracus* s. str., remarking that "their anterior eyes and square preglabellar area are quite suggestive of the Olenidae, notably *Angelina* Salter".[2] They differ, however, from *Angelina* in the entire character of the associated pygidia.

Provisionally *Keidelaspis* may be placed among the Olenidae.

Locality and Horizon.—Pueblo Viejo, Quebrada del Toro, Salta. *Leiostegium* zone, Upper Ozarkian.

Genus *Kainella* Walcott, 1924.

Kainella conica Kobayashi.

Plate VI, Fig. 2, 4.

Kobayashi's diagnosis of this species is as follows: "The specific characters are a long conical glabella with a narrow palpebral lobe, short frontal limb, narrow rim pointed at the median point of the frontal margin, and oblique anterior branch of facial suture." [1]

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[1] Kayser, E., 1897, pl. viii, figs. 1–4.
[2] Kobayashi, T., 1935*b*, p. 237.

The free cheeks, not previously known, have long genal spines, much longer than those of *Kainella meridionalis* Kobayashi, which they otherwise closely resemble.[2]

The postero-lateral limbs both of *Kainella conica* and *K. meridionalis* are fairly short, thus differing from the genotype, *K. billingsi* Walcott.[3] Walcott defined the genus as possessing a shallow second pair of glabellar furrows. In *Kainella conica* these furrows are deep and sharply defined, but in Kobayashi's figures they appear to be shallow probably owing to oblique illumination.

Locality and Horizon.—Angostura de Parcha, Quebrada de Incamayo, Salta. *Kainella* zone, Upper Ozarkian.

Genus *Leiostegium* Raymond, 1913.

Leiostegium douglasi sp. nov.[4]

Plate VI, Figs. 11–14.

Cranidium subquadrate in outline. Glabella convex both in the longitudinal and transverse directions, truncato-conical in shape, rounded in front and sharply defined by deep dorsal furrows. Glabellar furrows obsolete or faintly indicated. Occipital furrow and ring well developed.

Glabella in direct contact with the frontal margin without an intervening frontal limb. The frontal margin is slightly convex, with a rounded contour and about as wide as the occipital ring. Marginal furrow deep along the front of the glabella as well as along the anterior part of the fixed cheeks. At the junction of the marginal furrow with the dorsal furrows there is a small shallow pit at each side of the glabella.

Fixed cheeks convex, wide, and provided with a postero-lateral limb.

Eyes of moderate size, placed far from the glabella and nearer to the posterior than to the anterior margin. Ocular ridges faint, visible as narrow lines running from the eyes to the dorsal furrow, and joining the glabella some 3 mm. from its anterior end.

Anterior branches of the facial sutures subparallel from the eyes to the marginal furrow. Then, intramarginal for a short distance, cutting the frontal margin obliquely.

Associated pygidia semi-elliptical in outline, with strongly segmented axial lobe and smooth, convex side lobes. Margin wide, convex, and well defined. Articulating furrow of the lateral lobes well marked.

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[1] Kobayashi, T., 1935*a*, p. 65, pl. xi, figs. 16–17.

[2] Kobayashi, T., 1935*a*, pl. xi, fig. 8.

[3] Walcott, C. D., 1925, pl. xxii, figs. 1, 3.

[4] The species is named in honour of Dr. J. A. Douglas.

The axial lobe bears five or six segments and an articulating half-segment. The rings are very well defined near the anterior end of the pygidium, but they become less and less marked posteriorly. The axial lobe ends in an unsegmented, rounded, elevated stump, which just touches the inner edge of the margin. The lobe narrows posteriorly, and the first segment, as well as the half-ring, are bent anteriorly.

Dimensions.	*mm.*	*mm.*	*mm.*	*mm.*
Length of cranidium	13·0	—	—	—
Length of glabella	11·5	—	—	—
Width of glabella at front	6	—	—	—
Width of glabella at base	8	—	—	—
Width of fixed cheeks	4·5	—	—	—
Length of pygidium	—	12	21	8
Width of pygidium	—	19	—	13
Length of axial lobe	—	11	18	—
Width of axial lobe	—	5	9	—
Width of border	—	2	—	—

Observations.—The present species closely resembles *Leiostegium manitouensis* Walcott from the Ozarkian of Colorado (Manitou Limestone) and British Columbia (Chushina Formation).[1] *L. manitouensis* has, however, two pits on the dorsal furrows at each side of the glabella. The glabella is somewhat less conical and more subquadrate, the fixed cheeks are rather narrower, and there are no ocular ridges. The free cheeks differ from those of *L. manitouensis* in having the strong genal spine directed backwards and outwards.

The associated pygidia of *L. douglasi* resemble, like those of *L. manitouensis*, the pygidia of the Asaphids and especially those of *Bellefontia* Ulrich. They differ from that of *L. manitouensis* in the character of the segmented axial lobe. In the last-named species the first axial ring is not bent anteriorly and the axial lobe is not so well defined. Furthermore, the margin is narrower and less sharply defined. The pygidia are also comparable with those of *L. puteatum* Raymond.[2]

The present form can also be compared with some species of *Chuangia* Walcott, *Lisania* Walcott, and *Lloydia* Vogdes.

It resembles *Chuangia* in the truncato-conical shape of the glabella, which is seen in many species of that genus, but differs from it in the concave and narrow frontal limb which separated the glabella from the frontal margin, a limb that is entirely missing in *Leiostegium*. The palpebral lobes of *Chuangia* are much larger than in our form and the pygidia are very different. The cranidium, however, rather resembles that of *Chuangia nitida* Walcott[3] and *C. kawadai* Kobayashi.[4]

From *Lisania* it differs in having postero-lateral limbs which are

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[1] Walcott, C. D., 1925, pl. 23, figs. 12–19.
[2] Raymond, P., 1924, pl. 14, fig. 16.
[3] Walcott, C. D., 1933, pl. 17, fig. 21.
[4] Kobayashi, T., 1933*b*, pl. xi, fig. 1.

lacking in that genus. Furthermore, *Lisania* has narrow fixed cheeks and long palpebral lobes. The associated pygidia are also very different, showing segmentation both on the axial and side lobes. Our species strongly resembles the cranidium of *Lisania ? breviloba* Walcott,[1] although the frontal margin is slightly concave and the fixed cheeks much narrower.

The pygidium of our species is very similar to that of the genotype of *Lloydia*, *L. saffordi* Billings, as figured by Raymond [2] and Bradley,[3] although in *L. douglasi* the axial lobe is much narrower. The cranidium of *Lloydia* seems to differ in having the eyes near to the glabella.

L. douglasi can also be compared with *Leiostegioides raymondi* Kobayashi, but in this species the frontal margin is straight and the eyes are placed further forward.

Locality and Horizon.—Pueblo Viejo. Quebrada del Toro, Salta. *Leiostegium* zone, Upper Ozarkian.

Genus *Asaphellus* Callaway, 1877.

Asaphellus jujuanus sp. nov.

Plate V, Figs. 5, 9, 10, 14.

Cephalon semicircular in outline, with a well-defined concave border. The border is narrow near the genal angles, but increases in width towards the front margin, where it is much wider.

Cranidium flat or very slightly convex.

Glabella smooth, not defined in front, sloping gently down to the concave border. In some specimens dorsal furrows are seen in the shape of ill-defined, shallow depressions running forwards from the occipital furrow, passing some distance inside the palpebral lobe, and disappearing in front of the eyes. In other specimens these depressions are obsolete.

In some large cranidia the glabella is marked, near its posterior end, by two short lateral depressions, one to each side of the median line, which are parallel to the occipital furrow.

Median tubercle present on the glabella near the occipital furrow. In the holotype (Pl. V, Fig. 9) it is just barely visible as a very small and rounded pustule. In the cranidium of Plate V, Fig. 5, it takes the shape of a low, ill-defined and broad elevation, which can hardly be called a tubercle.

Occipital ring very narrow, more or less defined by a faint occipital furrow.

Facial suture isoteliform. The anterior branches diverge slightly from the eyes towards the front margin, then bend rather abruptly inwards and forwards and meet in an obtuse angle on the middle line producing a flat ogive.

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[1] Walcott, C. D., 1916, pl. 66, fig. 3*b*.

[2] Raymond, P. E., 1913, pl. vii, fig. 16.

[3] Bradley, J. H., 1925, pl. 1, fig. 9.

Posterior branches cutting the posterior margin nearer to the genal angles than to the dorsal furrow.

Eyes large, placed near the glabella and at the middle distance between anterior and posterior margins.

Free cheeks large. Genal angles produced into very short spines slightly bent outwards. Hypostome unknown.

Thorax with comparatively narrow axis. The axial lobe is less than one-third the total width of the thorax. Pleurae grooved and straight. Pleural extremities rounded and not bent forwards.

Pygidium flat, semi-elliptical in outline, with a wide and well-marked depressed border. Axial lobe narrow, more or less well defined by dorsal furrows that converge in the anterior part, but are parallel to each other in the posterior section; not raised over the side lobes and bearing traces of segmentation on its anterior part.

Lateral lobes smooth or with extremely faint traces of segmentation near their anterior end. Articulating furrow wide and well marked.

The collection comprises some twelve complete pygidia, the smallest being 5 mm. long and the largest 28 mm.

The general outline of all the pygidia is very similar. Only one specimen, 14 mm. long, shows a subtriangular tendency, recalling the type of *Isotelus* and *Isoteloides.*

In the smaller specimens traces of five axial rings are observable at the anterior part of the shield. These traces persist, even in specimens measuring 14 mm. in length. In the largest ones, however, they disappear almost entirely.

The same happens with the traces of segmentation on the side lobes, but these traces are even fainter that the axial ones and they are just visible with the aid of oblique illumination.

Dimensions.	(*a*)		(*b*)			
	mm.		*mm.*		*mm.*	
Length of cephalon .	9·5		—		—	
Width of cephalon .	19·5		—		—	
Length of cranidium .	9·5		25·0		18·5	
Width of cranidium .	14·0		37·0		? 26	
Width at palpebral lobes	15·0		14·5		9·8	
	mm.	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
Length of pygidium .	5	10	14	22	25	28
Width of pygidium .	9	18	23	38	44	45
	mm.					
Width of thorax . .	17·0					
Width of axial lobe .	15·5					

(*a*) Holotype cephalon and thorax.
(*b*) Paratype cranidium.

Observations.—The present form is easily distinguished from most of the smooth Asaphidae. *Isotelus* DeKay and *Isoteloides* Raymond are the only genera with which it could be confused.

It differs from *Isotelus* in the narrower thoracic axial lobe and in the presence of a median tubercle on the glabella.

Isoteloides has a pygidium with a prominent, well-defined axial lobe, very different from that of our species.

Its most probable generic position is, thus, in the genus *Asaphellus* Callaway.

The very short genal spines of *Asaphellus jujuanus* distinguishes it from all the species of *Asaphellus* of which the free cheeks are known.

From *A. perneri* Holub, *A.* (?) *coreanicus* Kobayashi, and *A. monticola* Raymond it differs in the course of the anterior branches of the facial sutures. In *A. perneri* the sutures converge, immediately in front of the eyes, towards the anterior margin.[1] In *A. monticola* they are parallel to each other[2] while in *A.* (?) *coreanicus* they strongly diverge towards the anterior margin.[3] In all three species the ogive made by the union of the sutures is more pointed than in the present form.

Asaphellus jujuanus seems to be closely allied with *A.* (?) *catamarcensis* from Northern Argentina and *A. tomkolensis* from South Chosen.

Locality and Horizon.—Quebrada de Chalala, Jujuy. *Asaphellus* zone, Tremadocian.

Genus *Basilicoides* nov.

Diagnosis.—Asaphidae with semi-elliptical cephalon. Large postero-lateral limbs. Facial suture isoteliform. Eyes small, placed at the middle distance between the anterior and posterior margins of the cephalon. Pygidium multisegmented, parabolical in outline, with about 14–15 deep furrows on the side lobes, which represent pleural grooves. Hypostoma unknown.

Genotype.—*Basilicoides taurinus* gen. et sp. nov.

Basilicoides taurinus gen. et sp. nov.

Plate VI, Figs. 1, 3, and Plate VII, Fig. 1.

Large size Asaphid, elliptical in general outline.

Cephalon semi-elliptical, flat, shorter than wide, and slightly shorter than the thorax, which likewise is shorter than the pygidium. Concave border wide and ill-defined, striated. Genal angles not known.

Glabella elongate, with parallel sides and semicircular anterior end. Each dorsal furrow visible as a shallow groove; its anterior part as a deep, curved, and well-defined furrow. The glabella seems to have been crushed in the only two specimens collected. In the large specimen of Plate VII, Fig. 1, it is possible, however, to observe quite clearly that a shallow furrow extends, at each side of the glabella, from some distance behind the eyes inwards and backwards, but do not meet along the middle line. The frontal lobe thus delimited is circular in outline.

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[1] Holub, K., 1911, pl. i, fig. 6*b*.

[2] Raymond, P., 1910, pl. xiv, fig. 8.

[3] Kobayashi, T., 1934*b*, pl. iv, fig. 12.

Occipital ring wide, as wide as the first thoracic ring, bounded by a shallow occipital furrow.

Eyes small, placed near to the glabella and at the middle distance between the anterior and posterior margins.

Facial suture isoteliform. Posterior branches cutting the posterior margin near the genal angles.

Postero-lateral limbs of fixed cheeks wide and long, marked with a deep and well-defined posterior groove.

Thorax much wider than long. Length less than half the width. Axial lobe narrow, about one-fifth of the total width, tapering slightly backwards. Pleural grooves strong, running diagonally from the anterior angles of the inner end to five-sixths the length of the pleura. Pleural extremities drawn out into long curved spines directed backwards.

Pygidium parabolic in outline. Axial lobe narrow and long, less than one-fifth of the total width at the anterior end. Its dorsal furrows converge in the anterior part, but become parallel in the posterior section. Axial lobe with about 20–22 rings. Side lobes with 12–14 broad and deep furrows.

In the well-preserved pygidium of Plate VI, Fig. 1, a very fine line can be observed running along the middle of each rib from axial extremity to distal end. This line probably represents the interpleural furrows and each rib is thus formed by the posterior half of one pleura and the anterior half of the next one. The deep lateral grooves are, then, probably pleural grooves as in *Basilicus* Salter and *Ogygitoides* Kobayashi.

Dimensions.	*cm.*	*cm.*	*cm.*
Total length of the trilobite	? 21·0	? 16·0	
Maximum width	? 15·0	—	
Length of cephalon	? 6·0	? 4·5	
Width of cephalon	—	—	
Width of cranidium	11·7	—	
Length of glabella	4·0	3·5	
Width of glabella at base	3·0	—	
Length of thorax	6·7	4·8	
Width of thorax (anterior end)	14·4	—	
Width of axial lobe of thorax	3·0	—	
Length of pygidium	8·0	6·7	7
Width of pygidium	13·6	—	11
Width of axial lobe	2·4	2·0	—

Observations.—The isoteliform suture at once distinguishes this genus from *Basilicus* Salter, *Parabasilicus* Kobayashi and *Basiliella* Kobayashi. It differs, furthermore, from *Parabasilicus* because in this genus the segmentation of the pygidium is obsolete.

Basiliella was erected by Kobayashi in 1934 with *Asaphus barrandi* Hall as genotype. Discussing this genus Kobayashi states that "although the facial sutures of *B. barrandei* are not exactly marginal, the interval not being very great, they are within the frontal margin and meet at a median point ".[1] Raymond and Narraway have figured an incomplete free cheek of *B. romingeri* Walcott (= *B. barrandi* Hall), stating that "the anterior limb of the facial suture shows as a line on the inner surface of the doublure ".[2]

Basiliella has been separated from *Basilicus* chiefly because of differences in the pygidium, which, according to Kobayashi, is semicircular in outline and shows "about ten ribs and furrows ".

The pygidium of the present form is of the *Basilicus* type, having 14–15 side furrows and parabolic outline. It cannot, however, be referred to *Basilicus* because this genus, as is shown by the genotype *B. tyrannus* Salter, has typical niobiform sutures.[3]

Kobayashi has distinguished three genera of *Basilicus*-like asaphids with forked hypostoma and isoteliform suture. These genera are *Ogygitoides* Kobayashi, *Pseudobasilicus* Reed, and *Pseudogygites* Kobayashi.

Pseudobasilicus Reed has large eyes placed near the articulating margin and semi-circular pygidium, as is shown by the genotype *P. lawrowi* (Schmidt) Reed.[4]

Pseudogygites was erected by Kobayashi with *Asaphus canadensis* Chapman as genotype. As the figures of this species given by Raymond show, the eyes are small but placed far backwards, their distance from the posterior margin being about one-quarter of the distance between the anterior and posterior margins of the cephalon.[5] Furthermore, the pygidium is semicircular in outline, and the axial lobe bears about twelve faint rings.

Ogygitoides agrees with the present form in having small median eyes. It differs from *Basilicoides*, however, in the steep inclination of the posterior branches of the facial suture and because the eyes are placed rather far from the glabella, as is seen in the genotype, *O. raymondi*.[6] The pygidium only shows faint lateral furrows, "more than 8" having been counted. The pleural extremities are rectangular.

Ogygites Tromelin et Lebesconte is the only *Basilicus*-like genus with an isoteliform suture and an entire hypostoma. The chief characters of this genus, taken from Tromelin and Lebesconte's description of the genotype *O. desmaresti* Brongniart [7] and Rouault's figures of the type specimen,[8] seems to be as follows : Hypostoma entire ; isoteliform suture ; eyes large, placed near the articulating margin ; pygidium pauci-segmented, with four or five faint or obsolete lateral furrows ; median tubercle on the glabella.

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[1] Kobayashi, T., 1934*a*, p. 464.
[2] Raymond, P., and Narraway, J. E., 1910, pl. xvi, fig. 1.
[3] Salter, J. W., 1864, pl. xxii, fig. 5.
[4] Schmidt, F., 1904, pl. iv, figs. 1–3.
[5] Raymond, P., 1913, pl. vi, fig. 1.
[6] Kobayashi, T., 1934*a*, pl. xliii, figs. 1, 4, and 5.
[7] Tromelin, G., et Lebesconte, P., 1875.
[8] Rouault, M., 1848.

These characters sharply distinguish *Ogygites* from the present form.

Judging by the multi-segmented, parabolic pygidium and the small median eyes, *Basilicoides* would seem to be an intermediate form between *Basilicus* and *Ogygitoides*.

"*Ogygia*" *liquensis* Hoek from Bolivia[1] is somewhat similar to *Basilicoides taurinus*, but the character of the facial suture is not shown in the figures given by Hoek nor mentioned in the description of the species.

Locality and Horizon.—Summit of Cerro Gólgota, Quebrada del Toro, Salta. Western flank of the mountain range separating the Quebrada del Toro from the Quebrada de Incamayo, Salta. *Basilicoides* zone. Llandeilian ?

Genus *Protopliomerops* Kobayashi, 1934.

Protopliomerops primigenus (Angelin) Kobayashi.

Plate V, Figs. 2, 3.

Outline of entire trilobite elliptical.

Glabella elongate-subquadrate, rounded in front and moderately convex. Dorsal furrows subparallel or slightly converging towards the front. Three pairs of well-marked, parallel lateral glabella furrows running obliquely backwards and inwards and discontinued at the middle. Frontal lobe evenly rounded in front and separated from the anterior margin by a deep groove.

Occipital ring narrow and well-defined. Eyes small, placed opposite the second pair of glabella furrows. Fixed cheeks broad, with rounded genal angles and wide posterior marginal furrow.

Surface of cranidium punctate.

Thorax with fourteen segments. The axis occupies slightly less than one-third the width and tapers very gradually towards the pygidium. Axial segments considerably bent forwards. Pleurae produced into strong spines gradually becoming longer and more backwardly curved towards the pygidium.

Pygidium nearly semicircular in outline. Axis with five segments and a triangular caudal termination which does not extend beyond the margin. The five pleural segments extending beyond the margin as long, strong, and backwardly directed spines.

Dimensions.	*mm.*	*mm.*	*mm.*
Length of cranidium . .	—	5·0	4·1
Width of cranidium . .	—	12·0	—
Length of glabella . .	—	4·6	3·8
Width of glabella at base .	—	3·6	3·0
Length of thorax . .	12·0	—	—
Width of thorax (maximum) .	13·0	—	—
Width of axial lobe of thorax	4·0	—	—
Length of pygidium . .	4·0	—	—
Width of pygidium . .	8·0	—	—
Width of axial lobe . .	2·5	—	—

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[1] Steinmann, G., and Hoek, H., 1912, pl. xiv, and p. 230.

Observations.—Plate V, Fig. 3, seems to show fifteen thoracic segments. What appears to be the first thoracic segment is, however, the posterior marginal border of the cranidium, which is sharply marked off from the rest of the head-shield by a wide posterior marginal furrow, as can be seen in Plate V, Fig. 2. The correct number of segments is thus fourteen.

These specimens seem to be indistinguishable from *Protopliomerops primigenus* (Angelin) Kobayashi from the Apatokephalus zone of Scandinavia.

They agree very well with some of the specimens figured by Moberg and Segerberg.[1]

They are also very similar to the somewhat smaller variety, *lamanskii* Schmidt, from the B_1 stage of the Baltic provinces of Russia.[2] The specimen represented by Schmidt as text-fig. 10B is very similar to that of Plate V, Fig. 3, of the present paper.

P. primigenus differs from the genotype, *P. seisonensis* Kobayashi, in having rounded genal angles instead of genal spines. Some specimens of *P. seisonensis* show, however, rather blunt or rounded spines.[3]

Locality and Horizon.—Quebrada de Chalala, Jujuy. *Asaphellus* zone, Tremadocian.

III. SUMMARY AND CONCLUSIONS.

The list of fossils described in this paper and their stratigraphical distribution is shown in the Table on p. 122.

The *Kainella* and *Leiostegium* zones of the Quebrada del Toro are the equivalent of the Late Ozarkian of Western North America.

The fauna of the arenaceous-calcareous beds of the marine-glacial deposits of the Saladillo group is not characteristic enough to enable an exact determination of the age. Nevertheless, from the stratigraphical position of these beds, they could be considered as indicating Upper Beekmantown age.

The lower part of the Parcha group, with the single determinable fossil *Basilicoides taurinus* gen. et sp. nov. has been provisionally referred to the Llandeilian.

The faunule of the *Asaphellus* zone of the Quebrada de Chalala shows affinities with part of the Tremadocian of England, the Tomkolian of South Chosen, and the upper zones of the "Ceratopyge-region" of Scandinavia.

The stratigraphical relationship between the *Kainella* and *Leiostegium* zones of the pre-Puna and the *Asaphellus* zone of Purmamarca is not known.

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[1] Moberg, J. C., and Segerberg, C. O., 1906, pl. 12 and 14.

[2] Schmidt, F., 1907, pl. i, fig. 13, and text-fig. 10*b*.

[3] Kobayashi, T., 1934*b*, pl. vii, fig. 11, and pl. viii, fig. 16.

Stratigraphical position / List of Fossils	Quebrada del Toro				
	Cardonal Group		Saladillo Group	Parcha Group	Q. de Chalala
	Kainella Zone	*Leiostegium* Zone	Arenaceous-calcareous Beds	*Basilicoides* Zone	*Asaphellus* Zone
CYSTOIDEA.					
Gen. et sp. indet.					x
BRACHIOPODA.					
Obolus ? lampazarensis		x			
O. (*Bröggeria*) cf. *salteri*					x
Lingulella ? sp. a					x
Lingulella ? sp. b		x			
Lingulella ? sp. c		x			
Eoorthis saltensis		x			
E. christianiae					x
E. ? putilliformis	x				
E. bifurcata			x		
GASTROPODA.					
Oxydiscus keideli			x		
Hyolithus sp. indet.		x			
H. (*Orthotheca*) *multistriatus*					x
Gen. et sp. indet.			x		
CEPHALOPODA.					
Endoceras sp. a			x		
Endoceras sp. b			x		
Endoceras sp. c				x	
TRILOBITA.					
Agnostus sp. indet.					x
Andesaspis argentinensis	x				
Keidelaspis saltensis		x			
Kainella conica	x				
Leiostegium douglasi		x			
Asaphellus jujuanus					x
Basilicoides taurinus				x	
Protopliomerops primigenus					x

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EXPLANATION OF PLATES V–VII.

Plate V.

Fig.

1.—*Hyolithus* (*Orthotheca*) *multistriatus* sp. nov. Dorsal face. × 7.

2, 3.—*Protopliomerops primigenus* (Angelin) Kobayashi. 2.—Cranidium, pygidium, and part of thorax, × 4. 3.—Thorax and pygidium, nat. size.

4.—*Obolus* (*Bröggeria*) cf. *salteri* (Holl) Walcott. × 1½.

5, 9, 10, 14.—*Asaphellus jujuanus* sp. nov. Nat size. 5.—Cranidium. 9.—Cephalon and part of thorax. 10 and 14.—Pygidia.

6.—*Lingulella* (?) sp. a indet. Nat. size.

7.—*Agnostus* sp. indet. × 7.

8.—Cystoidea gen. et sp. indet. Calycal plate and stem-joints. Nat. size.

11–13.—*Eoorthis christianiae* (Kjerulf) Walcott. 11.—Dorsal valve, nat. size. 12.—Ventral valve, nat. size. 13.—Ventral valve, showing bifurcations of the ribs, × 7.

Plate VI.

1, 3.—*Basilicoides taurinus* gen. et sp. nov. 1.—Pygidium, nat. size. 3.—× ¾.

2, 4.—*Kainella conica* Kobayashi. Free cheek and cranidium. Nat. size.

5–7.—*Keidelaspis saltensis* gen. et sp. nov. 5 and 6.—Cranidia, nat. size. 7.—Pygidium, × 4.

8, 9.—*Eoorthis* (?) *putilliformis* Kobayashi. 8.—Internal cast of ventral valve, showing dental plates, nat. size. 9.—Dorsal valve, × 1½.

10.—*Obolus* (?) *lampazarensis* sp. nov. Internal cast of dorsal valve. × 4.

11–13. *Leiostegium douglasi* sp. nov. Cranidia, free cheek, and pygidium. Nat size.

14.—Pygidia and cranidia of *Leiostegium douglasi* sp. nov.—Cranidia of *Keidelaspis saltensis* gen. et sp. nov. with *Hyolithus* sp. indet. Nat. size.

Plate VII.

1.—*Basilicoides taurinus* gen. et sp. nov. × ¾.

2.—*Endoceras* sp. a indet. Nat. size.

3.—*Endoceras* sp. b indet. Nat. size.

4.—*Lingulella* (?) sp. c indet. Nat. size.

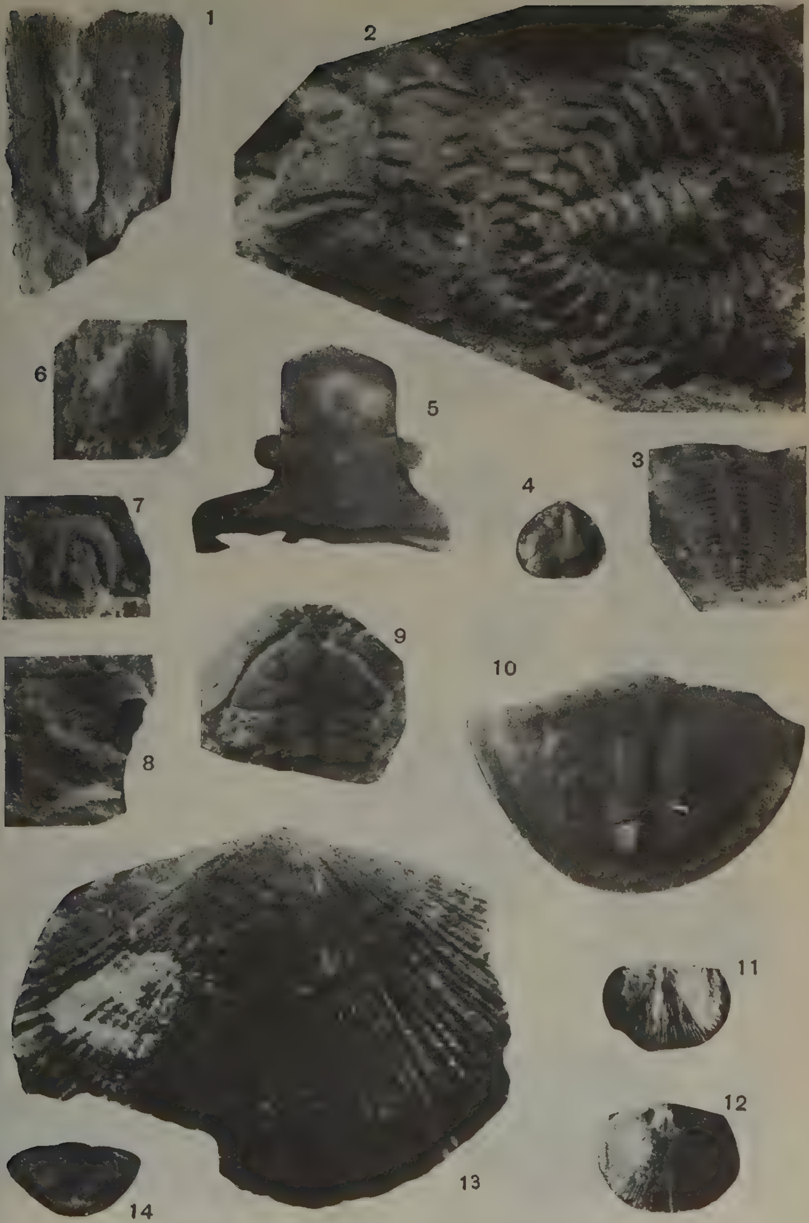
5.—*Eoorthis saltensis* (Kayser) Walcott. Ventral valves. × 1½.

6.—*Oxydiscus keideli* Kobayashi. Nat. size.

7.—*Eoorthis bifurcata* sp. nov. Dorsal valve. × 2.

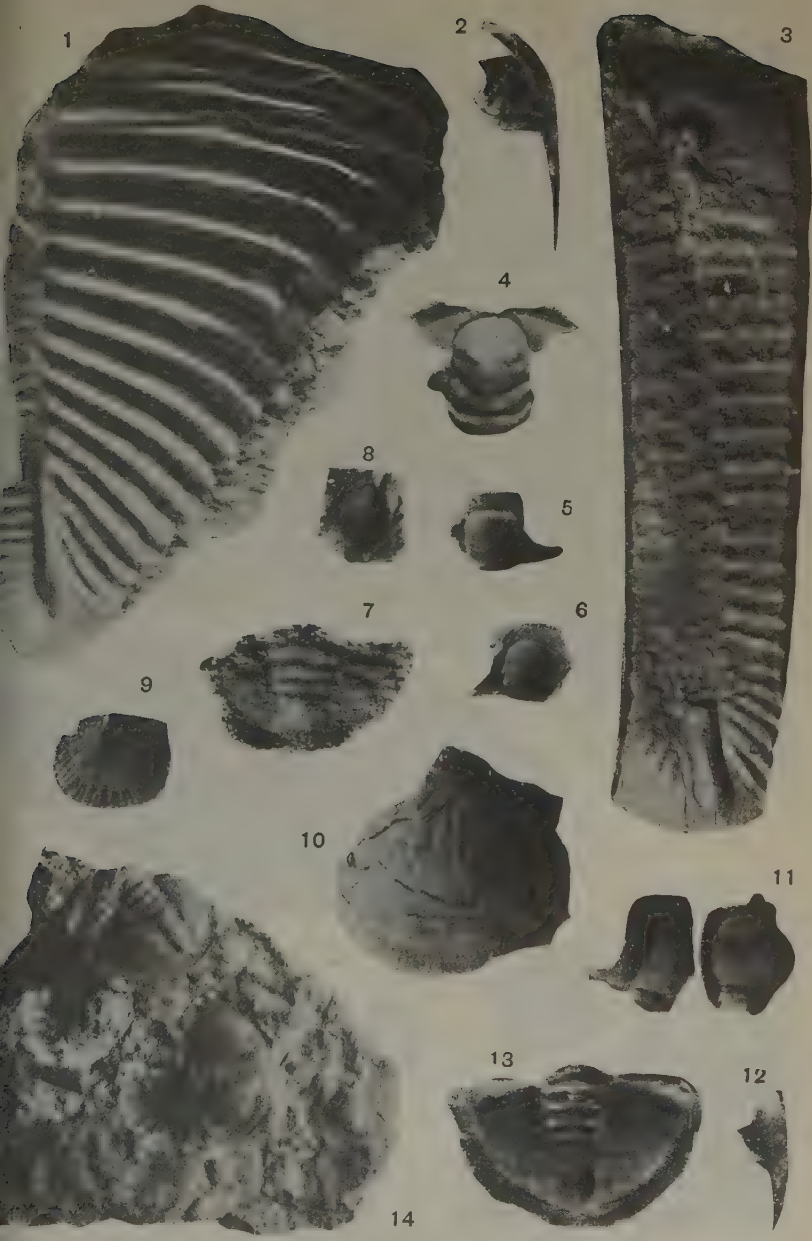
8–10. *Andesaspis argentinensis* Kobayashi. Cranidium and free cheeks. × 2.

11.—*Endoceras* sp. c indet. Nat. size.



ORDOVICIAN FOSSILS FROM ARGENTINA.

[*To face p.* 124.



Ordovician Fossils from Argentina.

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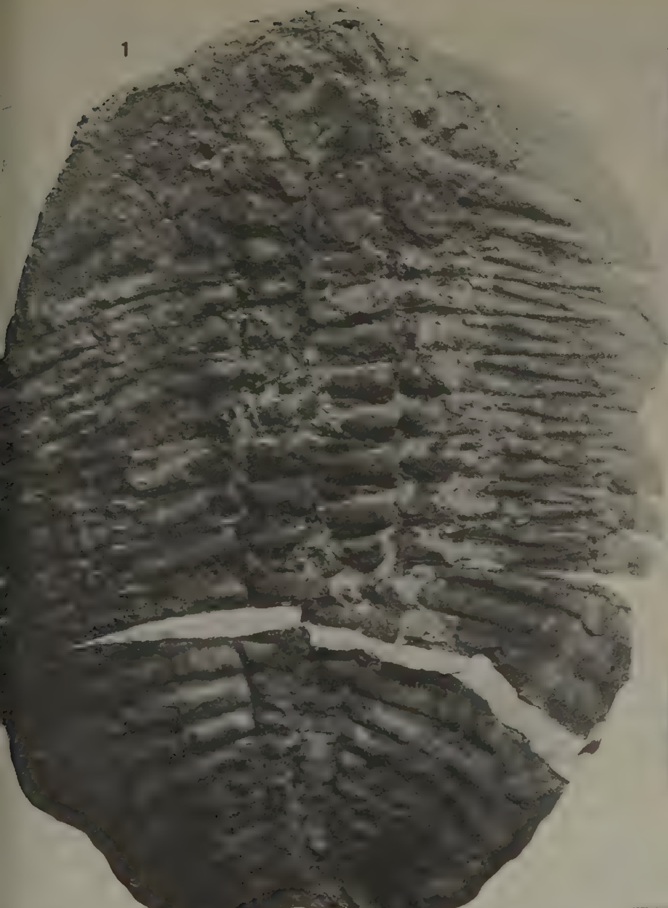

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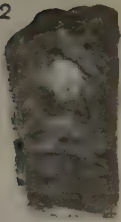

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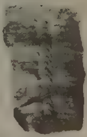

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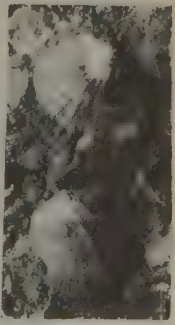

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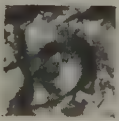

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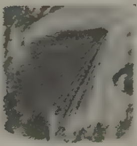

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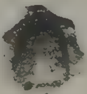

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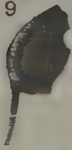

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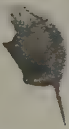

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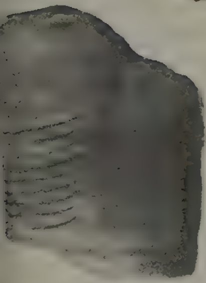

ORDOVICIAN FOSSILS FROM ARGENTINA.

Contributions to the Petrology of Barnavave, Carlingford, I.F.S.—2. An Occurrence of Quartz-bearing Syenite and its Xenoliths.

By S. R. Nockolds, Geology Department, Manchester University.

Introduction.

On the eastern side of Barnavave, at the immediate junction of the igneous mass with the surrounding limestone and about a quarter of a mile south of the fault which crosses the mountain, there is an isolated outcrop of a fine-grained, speckled rock which clearly invades the limestone at this point.[1] The rock includes xenoliths broken from the limestone and also others of igneous origin and smaller dimensions. Microscopical examination proves the rock to be a syenite of unusual character which carries a small amount of quartz. It is possibly the rock referred to by Harker.[2]

Petrology of the Syenite.

The syenite is composed essentially of microperthite, plagioclase, quartz, and aegirine-augite together with rather abundant sphene and some apatite (Fig. 1*a*). The *microperthite* is well developed with beautiful spindles of albite. It occurs in two generations as small and larger crystals and also as an edging to some of the plagioclase. A good deal of it is rendered turbid by a multitude of indeterminate dusty inclusions. The plagioclase occurs in fairly large hypidiomorphic crystals which may be veined and mantled by a more acid variety. It usually shows strong zoning, especially where edged with microperthite. The cores of such zoned crystals were found to range from $Ab_{53}An_{47}$ to $Ab_{68}An_{32}$, whilst the outer zones may be as acid as $Ab_{79}An_{21}$. This plagioclase is often encroached upon by myrmekitic intergrowths of extreme delicacy when it is not edged with the potash felspar. The *quartz*, which only occurs in small quantity, is present as little interstitial plates and contains large fluid inclusions. The *aegirine-augite* is present, for the most part, in small hypidiomorphic crystals, but some larger ones are also to be found. It is strongly pleochroic with $\alpha =$ bluish green, $\beta =$ bluish green, $\gamma =$ yellow green and is biaxial positive with 2V large. The extinction angle is variable with $\alpha \wedge c = 13\text{–}29°$ for the smaller crystals. Quite a number of these are zoned with pyroxene of deeper colour and lower extinction angle on the outside. The larger crystals may have $\alpha \wedge c$ ranging up to 34° and many are less deeply coloured. Amongst the accessories, *sphene* is the most important in idiomorphic and hypidiomorphic crystals which are slightly pleochroic from colourless to pale pink. These are closely associated with the pyroxene and may have cores of ilmenite. *Apatite* is common in small crystals and as minute needles enclosed in microperthite and plagioclase. There is a little *iron ore*, chiefly associated with the pyroxene, and finally there is some *albite* present as interstitial threads between many of the small microperthite individuals.

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[1] See sketch-map in Geol. Mag., LXXII, 1935, 290.

[2] A. Harker, *Petrology for Students*, Cambridge, 1923, 51.

Strictly speaking, the rock should be called a syenite-porphyry because the larger individuals of microperthite, aegirine-augite, and plagioclase form microphenocrysts which are set in a groundmass of the smaller microperthite and aegirine-augite crystals, together with the sphene and apatite, the interstitial quartz, and the interstitial threads of albite. In this respect the rock bears a striking resemblance to a syenite-porphyry described from the Tintic mining district, Utah.[1] The mode (volume percentages) of a typical specimen is given below :—

Microperthite .	76·3	Aegirine-augite .	13·4
Plagioclase . .	4·8	Sphene	0·7
Quartz . . .	3·9	Iron ore and apatite	0·9

The chemical composition of the rock is as follows :—

SiO_2 .	62·90
Al_2O_3 .	15·62
Fe_2O_3 .	0·94
FeO .	2·50
MgO .	0·53
CaO .	3·08
Na_2O .	4·17
K_2O .	8·65
TiO_2 .	0·56
MnO .	0·03
P_2O_5 .	0·08
$H_2O +$.	0·25
$H_2O -$.	0·25
	99·56

Norm.	
qu	0·78
or	51·15
ab	31·96
an	—
di	9·76
wo	1·28
ac	2·77
il	1·06
ap	0·34

Specific gravity : 2·66.

The rock is of some interest as it adds another occurrence of alkali-syenite to the few recorded from the Tertiary igneous rocks of the British Isles.[2]

PETROLOGY OF THE XENOLITHS.

Two kinds of xenolith are present in the syenite. There are inconspicuous xenoliths or xenolithic remnants of basic igneous rock and others, more noticeable, of limestone.

(*a*) *The Basic Igneous Xenoliths.*—The best preserved here are small xenoliths, some 5 × 3 mm. in size, of what was originally a fine-grained ophitic dolerite (Fig. 1*b*). In these the doleritic texture is partly retained in spite of the alteration to which they have been subjected. The plagioclase is lath-shaped and zoned for the most part, with cores varying from $Ab_{46}An_{54}$ to $Ab_{55}An_{45}$ and with outer zones up to $Ab_{75}An_{25}$. It encloses fairly abundant minute needles of apatite. The augite is partly ophitic and partly granular. It is green in colour, does not show much pleochroism, and has $\alpha \wedge c$ up to 45°. Towards the margins of a xenolith the augite may become deeper in colour and grade into aegirine-augite. A fair amount of iron ore is present in largish grains with flakes of biotite attached. Finally, there is a little interstitial microperthite in places. In addition to these xenoliths there are xenolithic remnants of coarser grain consisting of a crystal or two of zoned plagioclase together with green augite which may be rimmed with aegirine-augite. A study of the thin sections shows quite clearly that it is xenoliths and xenolithic remnants of this nature which have provided the microphenocrysts of plagioclase and pyroxene in the syenite. It will be remembered that the plagioclase still has cores of basic composition whilst the larger pyroxenes have a higher extinction angle and are not as alkaline as those forming the groundmass. These two components of the syenite are thus largely xenocrystal in nature.

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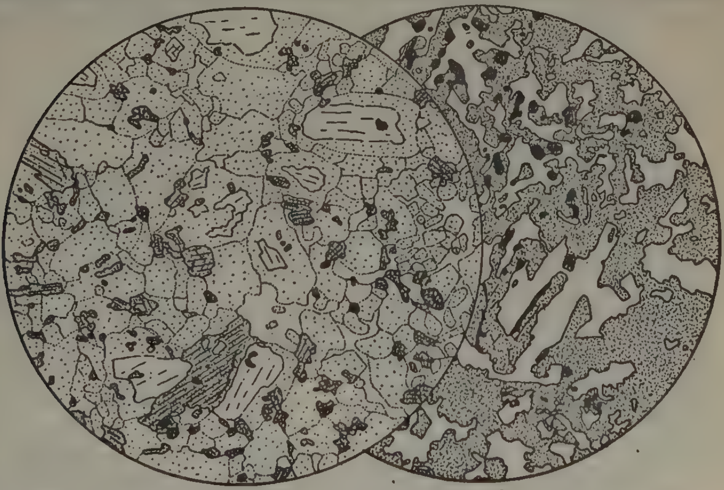
[1] W. Lindgren and G. F. Loughlin, *U.S.G.S., Prof. Paper*, 107, 1919, 68.

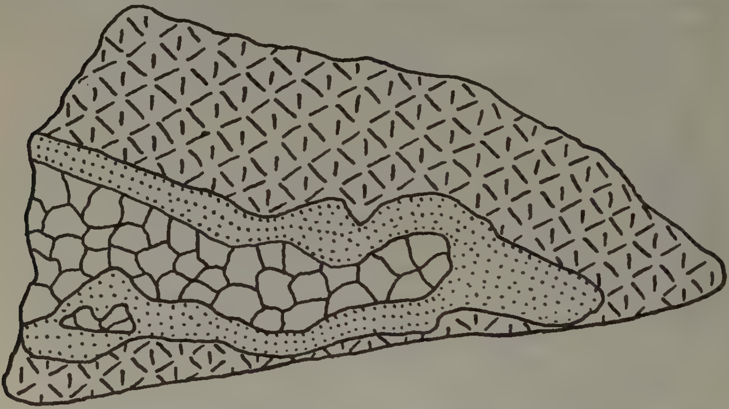
[2] "Tertiary Igneous Rocks of Skye," *Mem. Geol. Sur. U.K.*, 1904, 165. "Tertiary and Post-Tertiary Geology of Mull," *Mem. Geol. Sur. Scot.*, 1924, 189–191.



TEXT-FIG. 1.—(*a*) The syenite, showing aegirine-augite, some plagioclase (partly corroded), microperthite (lightly stippled), interstitial quartz, and albite (left blank) with accessory sphene and iron ore. Ordinary light × 10. (*b*) Recrystallized and impregnated dolerite xenolith in the syenite. The drawing shows green augite, abundant iron ore (often with marginal flakes of biotite), plagioclase, and a small amount of introduced microperthite (both these latter left blank). Near the centre there is a small area of coarser texture with less iron ore, which has escaped recrystallization and indicates the original texture of the dolerite. Ordinary light × 25.

(*b*) *The Limestone Xenoliths.*—The limestone xenoliths are more conspicuous than those of igneous origin and the largest found is illustrated in Fig. 2. In some cases the inner zone of such xenoliths has weathered away, leaving a hollow surrounded by the harder outer zone. These two zones are also displayed in striking fashion by the unweathered xenoliths. In the specimen illustrated the centre is occupied by a pale blue coarsely crystalline aggregate of calcite, whilst the outer zone, an obvious reaction zone, is pale pink in colour, hard and compact.

In thin section the inner zone resolves itself into a mosaic of large and smaller interlocking plates of calcite in which are set numerous small grains and granules of a diopsidic pyroxene (see Fig. 3*a*). This pyroxene is colourless, biaxial positive with 2V near 60° and with $\gamma \wedge c = 45°$. It may show small-scale diablastic intergrowth with the calcite. Its approximate chemical composition as calculated from the analysis of this inner zone is :—



TEXT-FIG. 2.—Diagrammatic sketch of hand-specimen showing limestone xenolith enclosed in syenite. The xenolith has an inner portion mainly composed of pale blue calcite, surrounded by a well-defined pink reaction zone (stippled in the drawing). The length of the xenolith as shown here is 2·8 inches.

		No. of metal atoms on basis of 60.			
SiO_2	45·31	Si	1·67	1·99	
Al_2O_3	7·68	Al	·32		
Fe_2O_3	3·41[1]	Fe'''	·09	1·13	2·11
MgO	18·76	Mg	1·04		
CaO	24·84	Ca	·98		
	100·00				

It is interesting to find that the pyroxene contains an appreciable amount of Al, all of which is replacing Si. The only other minerals present are a very occasional prismatic crystal of rutile and a few small specks of iron ore. This inner zone has the following modal composition: calcite 93·4, pyroxene 6·6 (volume percentage), or calcite 92·7, pyroxene 7·3 (weight percentage).

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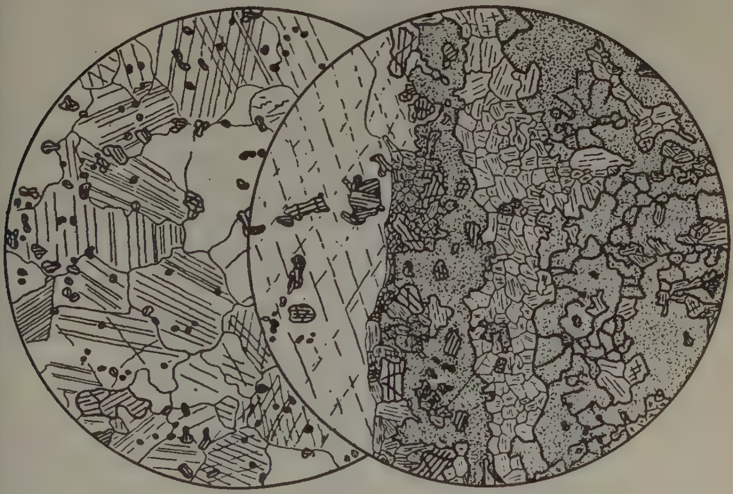
[1] All iron as Fe_2O_3.

The outer reaction zone can be divided into two portions under the microscope. The inner portion of the zone is mainly composed of wollastonite and garnet, both of which are colourless in thin section (see Fig. 3*b*). The junction between this and the inner zone of the xenolith is fairly sharp. The wollastonite is present in abundant hypidioblastic and granoblastic crystals whilst the garnet occurs as irregular masses containing abundant small inclusions of wollastonite and sometimes calcite. These two minerals are accompanied in places by a little diopside and interstitial calcite with, also, an occasional crystal of pale brown sphene and very minor amounts of iron ore. This inner portion passes gradually into the outer portion, lying next to the syenite, which consists entirely of an extremely delicate diablastic intergrowth of garnet and wollastonite (see Fig. 4).


a. *b.*

TEXT-FIG. 3.—(*a*) Inner portion of limestone xenolith, mainly composed of calcite with subordinate grains and granules of diopside. Ordinary light × 10. (*b*) Outer reaction zone of limestone xenolith with abundant garnet and wollastonite. On the left, the junction with the inner portion of the xenolith may be seen. Ordinary light × 23.

The mode of the entire outer zone as calculated from the chemical analysis is: wollastonite 54·4, garnet 37·0, diopside 5·8, calcite 1·3 (CaO excess 0·7, H_2O 0·3) = 99·5. The composition of the garnet is approximately $\text{Grossular}_{77}\text{Andradite}_{14}\text{Almandite}_{9}$.

Chemical analyses of the inner and outer zones of the limestone xenolith illustrated are given below, together with their norms :—

	I.	II.
SiO_2 .	4·25	45·75
Al_2O_3 .	0·72	7·12
Fe_2O_3 .	0·32[1]	1·63
FeO .	—	1·48
MgO .	1·76	1·07
CaO .	53·29	41·64
Na_2O .	n.d.	n.d.
K_2O .	n.d.	n.d.
TiO_2 .	*nil*	0·41
MnO .	*nil*	trace
P_2O_5 .	trace	0·24
H_2O .	0·15	0·23
H^2O .	0·08	0·06
CO_2 .	40·02	0·59
	100·59	100·22
Sp. Gr. .	2·734	3·004 (at 19·5° C.).

Norms :—

	I.	II.
an	1·95	19·46
di	3·67	7·32
woll	—	56·72
Ca. orth.	1·55	11·70
Mg. orth.	1·89	—
il	—	0·76
mt	—	2·32
hae	0·32	—
ap	—	0·34
cal	91·00	1·30

I. Inner zone of limestone xenolith. II. Outer zone of the same.

As the specific gravities of the two zones are known it is possible to compare unit volumes and thus obtain the absolute gains and losses which have occurred during the reaction of the limestone with the syenite. Ignoring H_2O the following figures are obtained :—

	III.	IV.	*Gains and Losses.*
SiO_2 .	4·23	50·28	plus 46·05
Al_2O_3 .	0·72	7·82	plus 7·10
Fe_2O_3 .	0·32	1·79	plus 1·47
FeO .	—	1·63	plus 1·63
MgO .	1·75	1·18	minus 0·57
CaO .	53·10	45·76	minus 7·34
TiO_2 .	*nil*	0·45	plus 0·45
MnO .	*nil*	trace	plus trace
P_2O_5 .	trace	0·26	plus 0·26
CO_2 .	39·88	0·65	minus 39·23

III. Analysis of inner zone recalculated to 100, ignoring water.
IV. Analysis of outer zone recalculated to 109·82, ignoring water.

These gains and losses show quite clearly that there was a considerable interchange of material between the outer portions of the limestone xenoliths and the syenite. The limestone has gained SiO_2, Al_2O_3, iron and minor amounts of TiO_2, P_2O_5 with traces of manganese from the syenitic magma, whilst the latter has received CaO, CO_2 and small quantities of MgO in exchange. It is at first sight somewhat remarkable that the limestone received no appreciable accession of alkalies in spite of the fact that it was lying in a highly alkaline medium. A little reflection, however, shows that such was not necessarily to be expected. The change from an almost pure limestone to a mineral assemblage which is stable in contact with an alkaline syenite will evidently not take place at once but rather through a succession of intermediate stages. Such a stage is represented by the outer zones of the xenoliths under discussion and an accession of alkali would not take place until the composition of the modified xenolith was more appropriate for the formation of aegirine-augite, etc.

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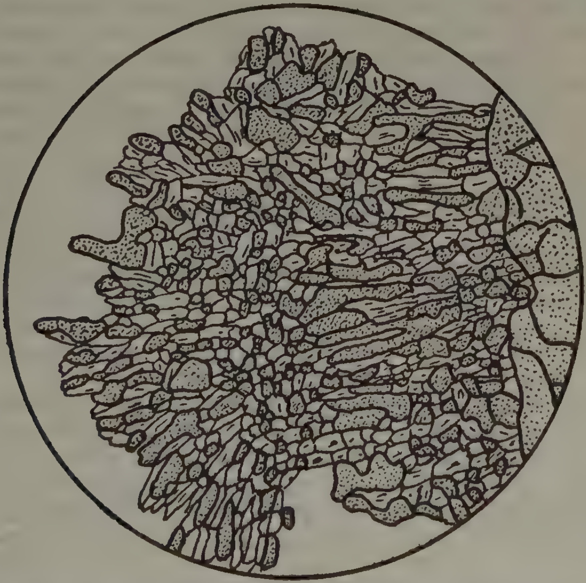
[1] All iron as Fe_2O_3.

The substances received by the magma were distributed through a comparatively large area when compared with the restricted outer zone of the xenoliths. In consequence the syenite shows little evidence of the incorporation. Quartz remains as a constituent right up to the contact with the limestone xenoliths, but within a short distance of the contact two minerals enter the syenite which are not normally present to any extent. These are calcite and pectolite, both occurring interstitially. Further effects of the entry of lime with its subordinate magnesia are difficult to find, but it is possible that their entry was responsible for slightly increased precipitation of pyroxene. Moreover, the abundance of sphene in the syenite as a whole may well be due in part to the entry of lime from this source, particularly when it is remembered that some of the sphene contains cores of ilmenite.



Text-fig. 4.—Detail of wollastonite-garnet intergrowth found at the contact of the xenolith with the surrounding syenite. Ordinary light × 200.

CONCLUSIONS.

The nearest exposures of igneous rock in the vicinity of the syenite are of a contaminated granite with the following modal composition (volume percentage): quartz 26·4, microperthite 46·4, plagioclase 17·1, hornblende 8·3, pyroxene 0·5, biotite 0·3, accessories 1·0. It does not appear likely that such a type could be so affected by reaction with limestone as to give rise to the syenite. There is little doubt that the syenite formed from a true syenitic magma, probably a partial differentiate from the normal granites of the area. The sequence of events is visualized as follows :—

(*a*) Intrusion of syenitic magma carrying small xenoliths of igneous origin which it had received at some greater depth. These suffered reaction and partial disintegration during their immersion, and xenocrystal pyroxene, plagioclase, and ilmenite were set free in the magma. The two former suffered further reaction, the pyroxene grading towards aegirine-augite, the plagioclase becoming more acid.

(*b*) While these reactions were in progress the syenite broke off limestone xenoliths on reaching its site of intrusion. Reaction with these was limited, partly because such reaction must have been of endothermic character.

(*c*) Sufficient interchange took place, however, to allow a certain amount of lime, magnesia, and CO_2 to enter the magma. It is believed that part of the lime together with some silica from the magma reacted with the ilmenite derived from the basic igneous xenoliths to produce sphene. At the same time the magma gave silica, alumina, iron, and minor amounts of titanium and phosphorus to the limestone xenoliths.

(*d*) Crystallization of the magma took place, the remaining lime and magnesia from the limestone helping to augment slightly the amount of aegirine-augite formed, whilst, close to the xenoliths themselves, interstitial pectolite and calcite formed at a late stage.

The syenite has thus been contaminated to some extent from two sources, namely, the basic igneous xenoliths and the limestone xenoliths.

Storm Waves and Shore-forms of South-Western Scotland.

By S. TING, Glasgow University.

THE effect of waves on a shore depends largely on the angle of approach, for the energy of the advancing waves tends to erode the headlands and drift the products of erosion into the bays. Wave refraction[1] applies to waves approaching the shore in any direction, but is only ideally developed in ordinary weather conditions or by approaching waves caused by distant storms. Locally developed storm waves usually approach the shore at an oblique angle to its general trend, owing to the failure of wave refraction and are the most effective where locally they meet the shore at right angles. Beach drifting will be in operation along the section of the shore which happens to be at an angle oblique to the direction of the approaching waves.

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[1] Johnson, D. W., *Shore Processes and Shoreline Development*, 1919, 74.

Storm waves have the power of lifting as is shown by the lifting of concrete blocks by wave pressure transmitted through crevices below the mass.[1] But there is another way of lifting materials which is seldom referred to in the literature, though well known to coastal engineers. When the waves approaching the shore impinge against a sloping wall or a cliff the wave is deflected vertically upwards to very high levels. The upward rush of surf charged with debris will carry the latter up to considerable heights and drop it at that level. Great damage may be done by the falling of the mass of water and the debris, because they acquire considerable energy when descending with accelerating velocity. This lifting power is important in connection with the discussion of the storm-built forms.

The islands of Islay, Jura, Colonsay, and Oronsay, of South-West Scotland, are exposed to the west and south-west, and afford interesting examples of storm wave deposits. The Clyde Estuary is protected by Kintyre and presents many shore-forms other than those of storm origin. The writer wishes to record some of the depositional features due to storm waves, and attempts to demonstrate the relative importance of these waves in the production of shore-forms.

STORM SHINGLE.

In an earlier paper,[2] the writer has classified storm shingle into storm beaches, storm shingle patches, and beach ridges. These three types are found in many places, at various heights above the present high-water mark. Storm beaches have a terrace form often with a slight landward slope. Shingle thrown into a ridge is called a beach ridge. Shingle having no definite shape and occurring only in patches at various heights belongs to the group of shingle patches. The writer has encountered such deposits in many places, notably on the western coast of Jura, where there are widespread areas of shingle, many of which are in ridge form, arranged in two or three terraces up to the height of more than 100 feet. Text-fig. 1 shows the shingle area found on the southern side of Loch Tarbert, Jura. The highest shingle patch is here a terrace rising only to about 30 feet above sea-level, while the lower shingle consists of two sweeping beach ridges. These deposits have blocked up a river to form a lake. They have been mistaken for raised beaches because of their height, but it is easily seen, especially in the case of the lower ridges, that they are built on a pre-existing cliff-backed marine platform of the third raised shoreline period. In places

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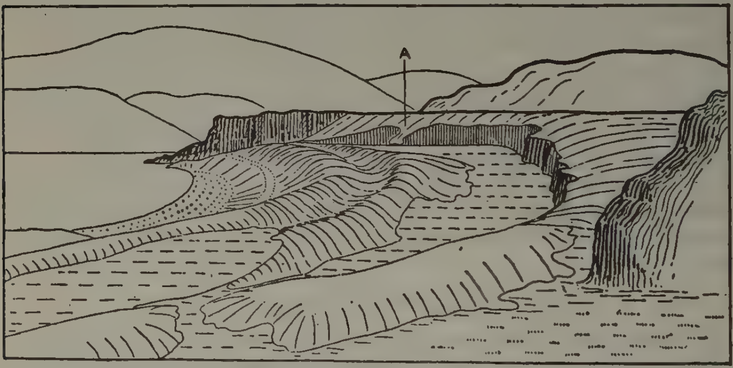
[1] Ibid., p. 66.

[2] S. Ting, "Beach Ridges of S.W. Jura," *Scot. Geogr. Mag.*, 52, 1936, 182–7.

(A, Text-fig. 1) the highest shingle is seen masking the face of the cliff. It is evident that the shingle has been laid down after the formation of the cliff and that it is not a part of the raised beach deposit.

Some other features also confirm their storm origin. The shingle consists mainly of ridges of asymmetrical section, being steeper at their rear slopes, which indicate the angle of repose when the materials were being thrown up into ridge form. This is a common feature in shore forms above ordinary high-water mark. Genuine beach deposits do not usually attain ridge form, and will not have the steeper rear slope, since they are not thrown up but rolled up by the waves. The Jura shingle consists of partially rounded cobbles which are scarred with concussion bulbs,[1] due to their beating one against another during deposition, while ordinary beach shingle is well-rounded and does not show such scars because it has suffered considerable wear by water action when rolling up and down a fairly steep foreshore slope. On a gentle slope similar waves may not be able to move the coarser elements, but storm waves will tend to throw rather than roll the materials and will thus transport them to higher levels. Another point is that much of the high shingle is found overlying hard rock in the form of a platform, which has no sign whatever of marine origin. On the landward side of this higher platform there is no marine cliff, a feature always associated with a wave-cut bench.



Text-fig. 1.—Shingle beaches and ridges, southern shore of Loch Tarbert, western Jura. Drawn by W. J. McCallien from a sketch by the author.

The beach ridges found $2\frac{1}{2}$ miles north of Feolin Ferry, south-west Jura, began to form at the close of the 25-ft. submergence, and continued to prograde during the rise of the land. Many of the low level shingle deposits are therefore interpreted as raised shingle, formed during the last emergence. The writer also believes that the higher shingle was also formed by the 25-ft. sea. The validity of the suggestion that shingle materials were thown up by a sea 25 feet higher than the present to a height of 70 or 80 feet above it may be doubted. But present-day records show that the surf of storm waves has frequently broken the windows of a lighthouse, 200 feet above the sea, at Unst, Shetland. Geikie also mentioned the broken windows of the Dunnet Head Lighthouse by stones swept with the 300-ft. rise of the storm surf.[1] Boulders 10 feet long are reported to have been thrown up into a mound 15 feet high on the top of a cliff 60 feet above the sea in the Orkneys.[2] It is therefore not at all surprising to suggest the throwing of much smaller cobbles to a height of 80 feet above the sea-level.

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[1] "The Geology of Jura, Knapdale, and N. Kintyre," *Mem. Geol. Surv. Scotland*, 1911, 127.

Bare shingle occurs all along the western coast of Jura from Cospach Bay in the north to a point 2½ miles north of Feolin Ferry in the south, a distance of about 18 miles. The sea bordering this part of the coast is shallow, being less than 20 fathoms to a distance of 15 miles from the coast. Immediately north of Cospach Bay, though it is open to wave attack, the sea rapidly deepens to 50 fathoms only a mile off the coast. During the 25-ft. submergence the sea was here some 4 or 5 fathoms deeper, but the contrast between the two types of submarine conditions still existed. It seems therefore that relatively shallow water has considerably influenced the formation of the storm-built forms. The coast again is open to the west, facing almost directly the Passage of Colonsay, through which the flood tide current runs. All the shingle areas are facing west and south-west, except those on the shores of Loch Tarbert. This implies that the dominant and prevailing waves most frequently came from the south-west, as happens at the present day. Loch Tarbert, however, is a sheltered loch and the explanation of its shingled beach is probably that the waves passing into the loch, which narrows rapidly, have had to force their way into the passage. Their speed has been increased, and they developed sufficient power to throw materials up to high levels.

To the west of Jura, on the islands of Colonsay and Oronsay, storm beaches and ridges are less frequent while sand dunes are abundant. The dunes, which are sometimes formed on a beach ridge foundation, often preserve the trend of the ridges. Such dune ridges on Ardskenish, South-West Colonsay, having a fairly regular trend normal to the south-west direction and, rising to uniform heights of about 40 feet, are probably formed on beach ridges. The central part of Oronsay is thickly covered with sand dunes, while on the southern part of the island grass-covered shingle areas are seen below a thin layer of blown sand. Storm shingle patches are, nevertheless, very abundant. They have no regular shape, vary in dimensions and height, and are occasionally mistaken for raised beaches. They have been brought up by waves and dropped on the ground a bove the reach of high water. Where the shingle is dropped, the ground, if composed of loose and soft material and especially dry blown sand, would probably be depressed slightly by the force and weight of the falling water and shingle. Later deposits would therefore fall on a cushion of shingle and be scarred and heaped up into patches, the middle part of which is presumably thicker than its outer margin. Most of these patches are present-day formations.

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[1] Geikie, A., *Text-book of Geology*, 3rd ed., Macmillan, 1893.

[2] "The Geology of the Orkneys," *Mem. Geol. Surv. Scotland*, 1934, 10.

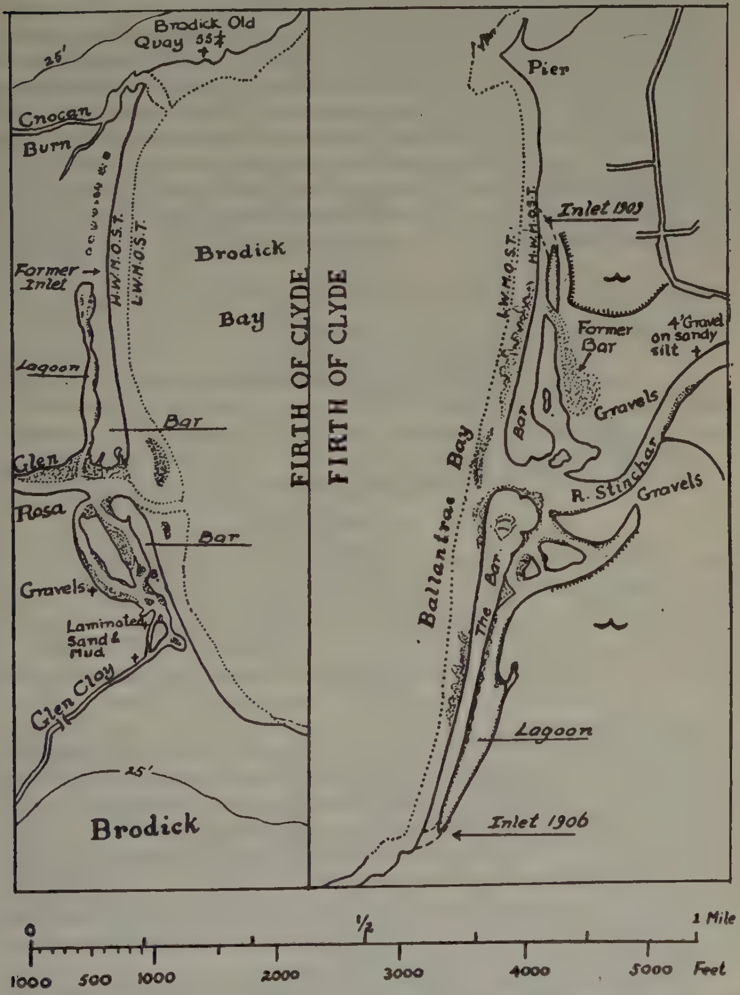
Storm beaches and raised beaches are often confused in geological literature, and this gives rise to erroneous measurements of the heights of raised beaches. At Uragaig, Colonsay, storm shingle overlies the raised beach gravels. The latter are not easily distinguished from the storm beach material except that they are mixed with finer particles and soil while the storm shingle consists of loose cobbles without any intervening soil.

Few storm beaches can be seen on the Kintyre coast or on the shores of the Clyde. A good example, however, occurs near Losset Park, Machrihanish, where the storm beach has a terrace form. Storm shingle occurs around the shore of Arran. At Tormore, south of Machrie, a small ridge runs from north to south, enclosing low-lying ground on which a small stream has been blocked to form a lake. Similar ridges along the coast from Tormore southward sometimes rise to 7 feet above high-water mark. Just below the projecting headland of the Doon Fort, a beach ridge is seen dividing northward into two branches and on the west side of Torrylin Water, Lagg, a 10 ft. high beach ridge fencing the shore is composed of coarse shingle.

BAY-HEAD BARS.

Turning from these exclusively storm-wave deposits we may consider some of the shore-forms built in the more sheltered bays.

In Brodick Bay, Arran, a bay-head bar (Text-figs. 2, 3), running from south to north, has two openings: the main one 700 yards north of Brodick Village is now the mouth of the Glen Cloy and Glen Rosa Waters, and the minor one at the northern end of the bar is occupied by Cnocan Burn. The bar is about 1 mile long and varies in width. It has a steeper landward slope and is composed of sand and fine gravels. The even surface of the bar is interrupted by many miniature ridges, curved landward at their distal end. The bar encloses an elongated lagoon. The southern portion of the lagoon is actually the course of the Glen Cloy Water, while the northern portion is a former river course. The bar has undergone many changes since it was initiated. Early in the nineteenth century it had its present appearance. In 1859 the southern portion was breached in three places, which were afterwards used by the Glen Cloy Water as outlets.[1] These temporary openings have later been silted up and both the Glen Cloy and the Glen Rosa Waters were deflected some 700 yards north of the present opening. Early in the present



TEXT-FIG. 2.—The Bay-head Bars of Brodick and Ballantrae.

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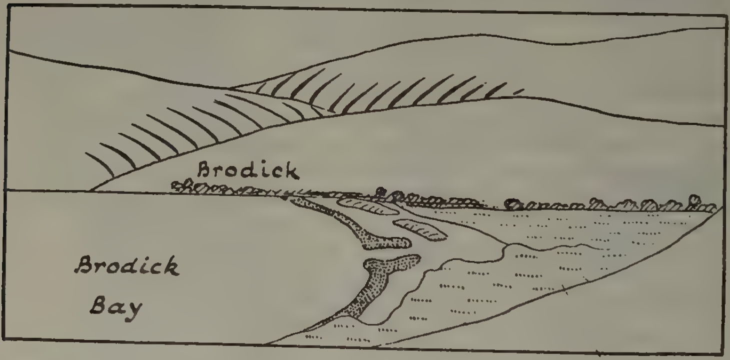
[1] The term "outlet" is equivalent to the term "inlet". The former term is used with reference to rivers draining into the sea through an opening in an off-shore form, while the latter is preferred in cases when the tidal currents or waves are considered.

century the opening shifted back to the present locality and left the northern course as an elongated lagoon. The minor opening has undergone few changes. The former Cnocan Burn originally had a strongly meandering course, which was artificially straightened, thus perhaps enabling it to maintain its outlet.

The bar is connected with the heavy deltaic deposition of the confluent rivers, which gave rise to the plain behind the lagoon, erroneously mapped by the Geological Survey as 15 ft. raised beach, and at the same time shallowed the water. The waves then broke on shallow water and had ample opportunity to throw the material up into a bar. Deposits examined in a few exposures along the river banks show that the plain is built of coarse gravels with carbonaceous inclusions. The difference between the grade of the materials which build the bar and that of the plain suggests that the features are of different origin. The sand composing the bar must have been derived from longshore transportation, though part of it may have resulted from the slow but continuous grinding of the deltaic gravels by the waves. Waves responsible for the formation of this bar came from the north-east and the materials being drifted along with the wave into the zone of perpendicular wave action were heaped up into the bar. Waves approaching from other directions would tend to fill the inlet and cause shifting of the latter either northward or southward.



TEXT-FIG. 3.—Brodick bar (dotted) looking south from the lower slopes of Goatfell.

A similar bar is found at the mouth of Stinchar Water, Ballantrae, South Ayrshire (Text-fig. 2). This bar is about a mile long, running southward from the Ballantrae Pier. The Stinchar Water maintains an outlet near the middle of the bar, which, however, appears to have been largely silted up, a crescent-shaped mound being seen across the mouth during low water. The bar faces W.N.W., and is composed of cobbles with ridges similar to those seen on the Brodick

Bar. On the northern portion of the bar and on the plain behind there are traces of a former ridge, truncated by the present bar, facing S.S.W. The southern portion of the bar is growing northward, as is indicated by the many successive recurvatures. Study of the old maps shows that early in the nineteenth century the mouth of the Stinchar Water was an estuary.[1] The 6 in. map of 1855 showed a well-developed bar with an opening approximately at the present site, but the northern portion was overlapping the southern part. Groome's map[2] (1884) showed openings at both ends of the bar, which was an island. On the 1 in. map of 1906 the northern opening was closed and a lagoon occurred behind it, while the Stinchar drained into the sea from the south. Three years later the southern opening was closed and a northern was opened. By 1912 the bar had attained its present configuration. It is clear that the Stinchar estuary has been silted up by coarse deltaic deposits due to the formation of the bar. Storm waves must have been responsible for its height, whilst the successive growth of the southern portion towards the north is probably due to beach drifting, because the materials seem to be rather coarse for longshore transportation.

Both the bars seen here are comparable with that of Drake's Bay, California, where delta filling of the enclosed water is still in progress.[3] A similar bar, but on a small scale, is seen in Sannox Bay, Arran.

TOMBOLOS AND SPITS.

A tombolo, 1 mile long, connects Davarr Island, Campbeltown, to the mainland. It runs north from the mainland for some 500 yards, then turns sharply to the E.N.E. and connects with the island at its western tip (Text-figs. 4, 5). It is composed of coarse shingle, lying on the northern and western edges of a mud flat, which, together with most of the tombolo, is submerged during high tide. The unsubmerged parts of the tombolo, only a few feet above the high-water mark, consists of the cuspate ends and the central re-entrant. The latter is made up of a succession of rings of ridges. The material of the tombolo is, in the writer's opinion, derived from the raised beach shingle on the southern coast of the island and the neighbouring northern coast of the mainland. In both localities the raised beaches are eroded into a low cliff. The waves come from the south-east, erode the raised beaches, and carry the debris northward until they encounter the eddy currents in Campbeltown Loch. The unequal development of the arms of the cuspate ridges points to a more vigorous action from the south-east. There is no indication of storm wave action, and the tombolo itself is the product of a delicate balance between the stronger inward drift over a former rock platform of shallow depth and the weak eddy currents in Campbeltown Loch. The shallowness of the water on the platform has considerable influence in diminishing the power and velocity of the inward drift, and the tombolo has been formed where the drift is checked by the eddy currents. The mud, as a result of the overflow of the eddy current during flood, accumulates on the platform. While accepting the formation of the tombolo as it is discussed above, Dr. McCallien, with whom the writer has discussed the above features in the field, differed from the writer in the explanation of the formation of the re-entrant. The writer is of the opinion that the re-entrant (Text-fig. 4) which marks the turning of the tombolo has a submerged rock base, towards which the original spits, whose junction produced the tombolo, were directed. The existence in the initial stage of two converging spits is indicated by the double Y formation of the cuspate ridges, each portion of the present tombolo being a former double Y-tombolo. Dr. McCallien doubts this hypothesis and suggests that the concrete foundation of the beacon is responsible for the greater accumulation of shingle around it. The northern portion of the tombolo shows traces of recent changes in shape. The telegraph poles, presumably planted on the

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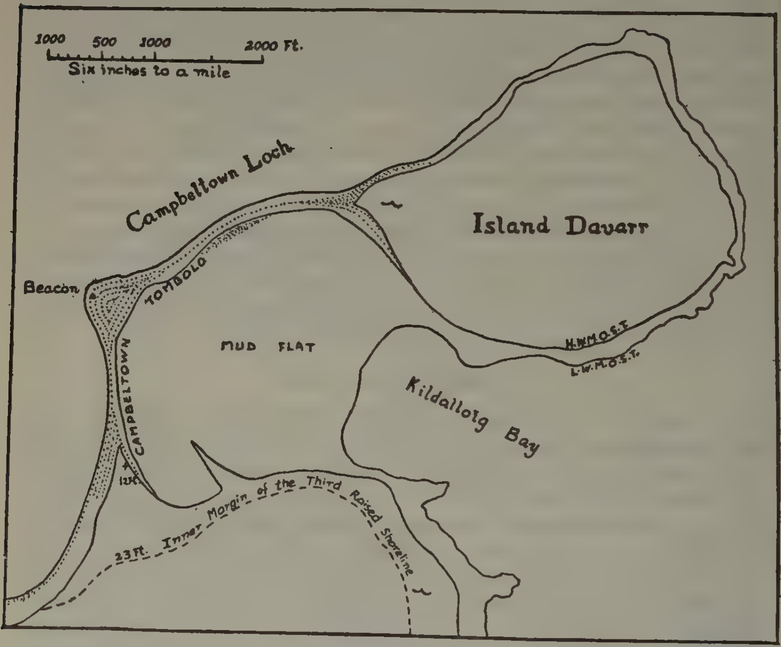
[1] Chambers, *Gazetteer of Scotland*, 1832, map.

[2] Groome, *Ordnance Gazetteer of Scotland*, 1884, map.

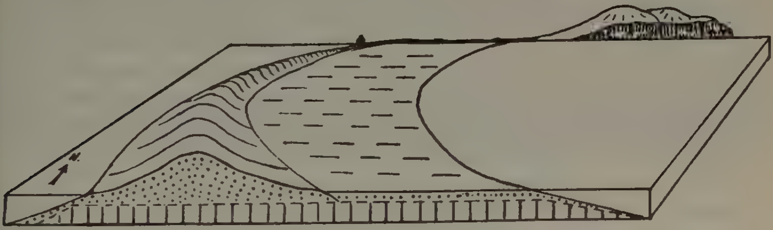
[3] Gulliver, F. P., "Shoreline Topography," *Proc. Acad. Art. and Sci.*, 34, 1898–9, pp. 208–209, 227, 232, figs. 21, 31.



Text-fig. 4.—Map of Davarr Island and Campbeltown Tombolo. Dotted lines indicate both simple and cuspate ridges.

crest-line of the shingle, are now situated on the sides of the ridge and some even on the mud flat.

A typical spit occurs in the head of Loch Indaal, Islay, pointing to the south. It is known to have existed a long time with no appreciable changes. Another spit occurs behind a dyke, just south of Kildonan Hotel, South Arran. The dyke stretches out into the sea and collects shingle on its leeward side. On the crest of the ridges the shells are arranged in lines with many short branches pointing to the north.



TEXT-FIG. 5.—The Campbeltown Tombolo during low water.

CONCLUSIONS.

The writer believes that storm waves alone are responsible for the shore-forms constructed at high levels. The storm waves which approach a shore are deflected upslope or thrown up against the cliff, and so are able to build shore-forms above high-water mark.

It is, however, difficult to draw a line between storm waves and normal waves, the difference being one of degree. In the case of Brodick Bar, wholly composed of fine sand, it seems that the material has been sorted by the waves and not thrown up by storms. Furthermore, the successive spurs of Ballantrae Bar need an explanation involving either Longshore current- or beach-drifting. For the production of under-water forms such as tombolos and spits storm waves are not necessary. It is perhaps from the detailed study of their modes of formation of shore deposits that one may find the means of distinguishing between the effects of storm and normal waves.

The writer wishes to express his thanks to Dr. G. W. Tyrrell, Dr. W. J. McCallien of the Geology Department, and Mr. G. Bowen, of the Geography Department of Glasgow University, for their kind assistance in the preparation of this manuscript.

REVIEW.

ENGINEERING GEOLOGY. By H. RIES and THOMAS L. WATSON. 750 pp., 271 text-figures, and 88 plates. Fifth edition, 1936. New York: John Wiley and Sons, Inc. (London: Chapman and Hall, Ltd.) Price 25*s.*

THIS well-known work is so firmly established as a textbook of geology for engineers, that the appearance of a fifth edition calls for little comment. On turning over its pages, one is again impressed by the wealth of skilfully summarized information which it contains on almost all branches of geology. As in previous editions, there is a generous supply of excellent illustrations, and the references are well chosen and up to date. Since the book is written primarily for North American readers, both the illustrations and references are naturally drawn mainly from American sources.

M. B.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY.

Exhibits.

(1) A device for counting mineral grains. By Mr. A. T. J. Dollar.

(2) A modified Kunitz centrifuge mineral separator. By Miss A. J. Hall.

Papers.

(1) " The potash-soda felspars." By Dr. Edmondson Spencer.

Optical properties and chemical composition of twenty-six potash-soda felspars have been determined. In the orthoclase-microperthites there is almost linear relation between specific gravity and optical properties and Ab-content. Specimens were heated (*a*) to near melting for a short period, and (*b*) for several days at 1075° C. Refractive indices decrease on heating between 400° and 850° C., and *d* also decreases. Heating to 1120° produces little further change. Very slow cooling from 800° to 350° restores the schiller and the lost refractive index and sp. gr. It appears that perthite can be dissolved and re-precipitated more readily than has been thought possible.

A structural explanation of the formation of perthite lamellae is offered.

A new equilibrium diagram for temperatures down to 800° C. is given. It is argued therefrom that residual granite magma at about 800° in presence of much water and free silica splits gradually into a soda-rich and a potash-rich fraction. The occurrence of potash-felspar crystals in xenoliths, the origin of the microcline of pegmatites, of " vein " perthite, and of quartz-microcline intergrowths are other points discussed.

(2) " Paregenesis of cookeite, hydromuscovite and free gold from Ogofau, Carmarthenshire." By Dr. A. Brammall, Mr. J. G. C. Leech, and Mr. F. A. Bannister.

Cookeite, not hitherto recorded as a British species, is associated with hydromuscovite, auriferous pyrite and mispickel, blende, galena, quartz, and free gold at the Roman Deep Mine, Ogofau, where, at depth, cookeite-deposition overlaps a mica-zone. The spectrograph of the mixed sulphides reveals (*inter alia*) tin, boron, antimony, and bismuth.

Cookeite is probably monoclinic (pseudo-hexagonal) with cell-sides *a* 5·13, *b* 8·93, *c* 28·30 A°, β near 90°. The unit cell contains 4 $LiAl_4Si_3AlO_{10}(OH)_8$ and the crystal-structure is akin to the chlorite rather than to the mica type.

In the hydromuscovite the usual $(OH)_4.K_2$-group takes the form $(OH)_{4+x}K_{2-y}$.

(3) " Note on an optically-positive hypersthene from Manchuria." By Dr. K. Tsuru and Mr. N. F. M. Henry.

The most iron-rich member of the orthorhombic pyroxenes yet discovered, 88 per cent $(Fe,Mn)SiO_3$. The name " orthoferrosilite " is proposed.

(4) " A note on an interesting occurrence of lawsonite in glaucophane-bearing rocks from New Caledonia." By Dr. Germaine A. Joplin.

Lawsonite occurs replacing felspar, associated with glaucophane and original augite. It appears that glaucophane-schists may be derived from calcic rocks, to which the lawsonite-glaucophane assemblage may stand in the same relation as does the well-known epidote-albite assemblage.

(5) " An occurrence of the mineral pumpellyite in the Lake Wakatipu region, western Otago, New Zealand." By Mr. C. Osborne Hutton.

Pumpellyite has been recognized as an important constituent of some schists and schistose greywackes. It appears to be formed concomitantly with albitization of plagioclase under conditions of low grade dynamo-thermal metamorphism.

(6) " The tektite problem." By Dr. J. L. Spencer.

Fused material on surface of meteorites is ablated as quickly as formed leaving only a film to solidify as glass. Tektites could, therefore, not have been completely fused and shaped in the Earth's atmosphere.

GEOLOGICAL SOCIETY OF LONDON.

Medals and Awards.

The Wollaston Medal to Professor Waldemar Lindgren, of the Massachusetts Institute of Technology, for his researches " concerning the mineral structure of the earth ", and especially concerning the problems of metasomatism, contact ore-deposits, and the application of physical chemistry to ore-deposition.

The Murchison Medal to Dr. Leonard James Spencer, in recognition of the value of his original contributions to mineralogical science and of his services to the publication of mineralogical literature.

The Lyell Medal to Mr. Linsdall Richardson, for his studies of the Jurassic rocks of Great Britain.

The Bigsby Medal to Professor Cecil Edgar Tilley, in recognition of the value of his researches, especially in the petrology of the metamorphic rocks.

The Wollaston Fund to Dr. Donald Parkinson, for his researches on the stratigraphy and palaeontology of the Slaidburn and Clitheroe areas.

The Murchison Fund to Mr. Stephen Henry Straw, in recognition of the value of his investigations into Silurian stratigraphy and the relations of the Silurian and Devonian rocks in the Welsh borders and the Midlands.

The Lyell Fund to Mr. James Frederick Jackson for his contributions to the palaeontology of the rocks of the Isle of Wight, and Dr. Mabel Elizabeth Tomlinson, for her researches on the Glacial and post-Glacial deposits of the Midlands.

CORRESPONDENCE.

THE NAME OF A FOSSIL CAT-FISH.

Sir,—Recently I published a description of the skull of a cat-fish from the early Eocene beds of North-west Nigeria, referring it to a new genus, which I named *Macronoides*, owing to its resemblance in certain respects to the living *Macrones* Duméril (" Fossil Fishes of Sokoto Province," *Bull. Surv. Nigeria*, Bulletin 14, 1934, p. 53). I now find that this name has already been used for a living cat-fish of the same family (Hora, *Rec. Indian Museum*, Bull. 22, 1921, p. 179), and I propose, therefore, to rename the fossil *Eomacrones*.

Errol I. White.

Department of Geology,
British Museum (Natural History).
5th December, 1936.

THE AGE OF THE HOWTH ROCKS.

Sir,—In the issue of this Magazine for December, 1936 (p. 546), the expression " Greenly proposes a pre-Cambrian age " seems to convey an impression of a more definite opinion than I have ever held. Perhaps the word " suggests " would convey my meaning better. My words in *The Geology of Anglesey* (p. 896) were : " . . . Howth Hill by Dublin, where there is little doubt that we can recognize the Gwna Beds." Could I re-edit that book I think that I would substitute " where it would appear that ".

The suggestion of the author that the Gwna quartzites may possibly be of aeolian origin is very welcome, and may prove illuminating, but will need to be considered in connection with all the features of that heterogeneous group.

Edward Greenly.

Bangor, North Wales.
7th December, 1936.

THE

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ORIGINAL ARTICLES.

Type Specimens of Palaeozoic Corals from New South Wales in W. B. Clarke's First Collection, and in the Strzelecki Collection.

By Dorothy Hill, Associate of Newnham College, Cambridge.

IN this paper is given a revision of all but one [1] of the corals in the Rev. W. B. Clarke's first collection of fossils from New South Wales; the collection was placed by him in the Woodwardian Museum at Cambridge in 1844, and was described by M'Coy (1847). The types are still preserved at the Sedgwick Museum, Cambridge. A description is also given of the holotype of *Amplexus arundinaceus* Lonsdale, which was collected from New South Wales by Strzelecki in 1842, and is now in the British Museum (Natural History), London. The species are distributed as follows: 1 ? Permian, 1 Lower Carboniferous, 1 Devonian, and 1 Silurian or Lower Devonian.

Genus *Amygdalophyllum* Dun and Benson.

Amygdalophyllum Dun and Benson, 1920, pp. 339–341.
Amygdalophyllum; Hill, 1934, p. 67.

Genotype.—*Amygdalophyllum etheridgei* Dun and Benson, 1920, pp. 339–341, pl. xviii, figs. 2–6, *non* fig. 1, Lower Carboniferous, Babbinboon, New South Wales.

Diagnosis.—Simple Rugose corals with a wide fine-tissued dissepimentarium, with numerous long straight septa, a remarkably large solid columella, and incomplete conical tabulae. Rare diphymorphs may occur.

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[1] The Lower Carboniferous *Cladochonus tenuicollis* M'Coy, which will be described by Professor L. B. Smyth and myself in a paper on *Cladochonus* and related genera.

Distribution.—Species placed in the genus are *A. nantanense* Huang (1932, p. 115, pl. i, figs. 2*a*–*b*) from the Uralian of Northern Kuangsi, South-West China, *A. wangi* Chi (1935, p. 23, pl. ii, fig. 4) from the Weiningian (Middle Carboniferous) of Yunnan, South-West China, and *A. quiringi* Weissermel (1935, p. 274, pl. 22, fig. 1) from the Upper Carboniferous (Moscovian) of North Spain. *Echigophyllum* Yabe and Hayasaka in Hayasaka (1924, p. 20, pl. iv, figs. 5–7) from the Anthracolithic Limestone of Ômi-mura, Echigo, Japan, is probably synonymous with *Amygdalophyllum*. Morphologies which are closely comparable, and in some cases possibly synonymous, with *Amygdalophyllum* are the Lower Carboniferous *Koninckophyllum* from Europe, Asia, and North America, the Russian Middle and Upper Carboniferous species placed by Stuckenberg (1888 and 1905) in *Rossophyllum* and *Axophyllum*, some of the Middle and Upper Carboniferous species from the Carnic Alps placed by Heritsh (1936) in *Lophophyllidium*, *Rossophyllum*, *Lophophylloides*, *Carniaphyllum*, *Geyerophyllum*, and *Carinthiaphyllum*, and the Chinese Middle Carboniferous (Weiningian) *Kionophyllum dibunum* Chi and *Axophyllum centrotum* Chi (1931).

Amygdalophyllum thomsoni (de Koninck).

(Text-figs. 1–5.)

Axophyllum (?) *thomsoni* de Koninck, 1877, p. 143, pl. 5, fig. 3. [Lower] Carboniferous. One specimen from Jervis Bay, and a second from Colocolo, N.S.W.

Axophyllum (?) *thomsoni* de Koninck (translated by David, etc.), 1898, p. 109, pl. v, fig. 3.

Neotype (here chosen).—A 6979, Sedgwick Museum, Cambridge; W. B. Clarke collection, presented 1844; Lower Carboniferous, Colocolo, New South Wales. De Koninck's two syntypes were purchased by the Government of New South Wales from W. B. Clarke, the collector, and were later destroyed in the burning of the Garden Palace on 22nd September, 1882. Other specimens used in the present description were A 6980–3, Sedgwick Museum, Cambridge (W. B. Clarke collection, presented 1844; Lower Carboniferous, Colocolo, New South Wales).

Diagnosis.—Cylindrical *Amygdalophyllum* with a narrow dissepimentarium and with septa strongly dilated in the tabularium.

Description.—Simple Rugose corals, with a short curved trochoid apical portion and a straight cylindrical upper portion. The specimens are incomplete and crushed; the largest fragment is 8 cm. long. The average diameter is 20 mm. There are forty to fifty long major septa, attenuate in the dissepimentarium, but dilated in the tabularium, dilatation decreasing towards the axis. They reach or almost reach the columella, and their axial edges are slightly turned aside. The minor septa are attenuate and only one-third as long as the major septa.

The cardinal fossula is well marked by the shortness of the cardinal septum and the decrease in width of the dissepimentarium.

The concentric dissepiments are shallowly channelled, and are steeply inclined towards the axis; they are developed in a zone as wide as the minor septa, and the innermost series is usually dilated. The tabulae are large and domed, and steeply inclined towards the dissepimentarium. They may be complete or incomplete, and some are dilated. The columella is large, oval in section, and elongate in the fossular plane. It is composite, formed of a dilated median lamella and the swollen discrete ends of the major septa. These ends may abut directly on to the median lamella, or be separated therefrom by a small tabella, when the columella becomes vesicular (Text-figs. 1 and 4).

The young stage (Text-fig. 5) differs from the adult by the absence of a dissepimentarium.

Septal Structure.—In the tabularium the dilated septa appear much altered by re-crystallization, but they are presumably pycnactoid. The sclerenchyme dilating the inner series of dissepiments is continuous with the sclerenchyme forming each side of the septum.

Remarks.—All the specimens are badly crushed, so that the figures given are imperfect. There can be no doubt that this species is the one described by de Koninck as *Axophyllum* (?) *thomsoni* sp. nov., although only one of the specimens (A 6983) shows the axial ends of the minor septa abutting on to the major septa as described by de Koninck. The species is distinguished from other *Amygdalophylla* by its cylindrical corallum and narrow dissepimentarium.

Genus *Disphyllum* de Fromentel.

Disphyllum de Fromentel, 1861, p. 302.
Disphyllum; Lang and Smith, 1935, p. 544.
Genolectotype.—*D. goldfussi* (Geinitz); Lang and Smith, *loc. cit.*

Diagnosis.—" Phaceloid Rugose corals in which increase may be lateral or calicular; the septa rarely reach the axis, but are usually long and typically thin; the tabulae are sometimes complete, though generally incomplete and differentiated into a transverse axial, and an inclined periaxial, series; with dissepiments typically small, strongly arched, sometimes of one, but frequently of two, kinds: an inner, single series of globose, distally directed dissepiments, and an outer series of flat or arched dissepiments." (Lang and Smith, *loc. cit.*)

Disphyllum arundinaceum (Lonsdale).

(Text-figs. 6, 7.)

Amplexus arundinaceus Lonsdale, in Strzelecki, 1845, p. 267, pl. viii, fig. 1; [Middle ? Devonian], Barber's [Creek], Shoalhaven [River], New South Wales.

non *Amplexus arundinaceus* Lonsdale in M'Coy, 1847, p. 228, which is *Tryplasma dendroidea* Etheridge (see p. 152).

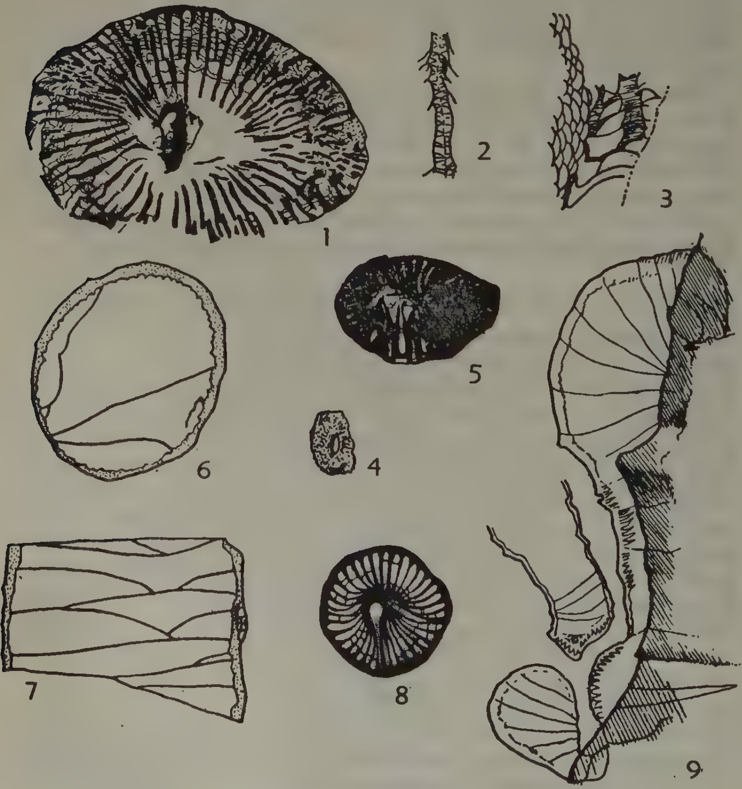
non *Zaphrentis* (*Plerophyllum* ?) *arundinaceus* (Lonsdale) in Etheridge, 1891, p. 9, pl. viii, figs. 1, 2; pl. ix, figs. 11–13; from the Permian of N.S.W.

non *Caninia arundinacea* (Lonsdale) in Koker, 1924, p. 12, pl. iv, figs. 1–5, pl. i, figs. 7, 7*a*; text-figs. 9, 9*a*, 10, 10*a*, 10*b*; from the Permian of Timor.

Holotype.—British Museum, R 90067, with slide 31070. This is the only specimen known.

Diagnosis.—*Disphyllum* like *D. geinitzi*, but with septa dilated to form a narrow peripheral stereozone.

Description.—The specimen, collected by Strzelecki, is a piece of dark grey limestone, so altered by metamorphism that the coral structure is almost obliterated. The fragmentary corallum is



TEXT-FIGURES 1–9.

phaceloid, the corallites being straight and parallel, and slightly compressed, with diameters of 14 and 12 mm. They are enclosed in a stromatoporoid or bryozoan. The longest fragment is 50 mm. The epitheca has rounded longitudinal ribs, and is transversely striated, and there are no obvious connecting processes.

The septa are short and dilated, forming a peripheral stereozone 1 mm. wide, but they may occasionally continue towards the axis as straight, attenuate, low ridges along the surfaces of the tabulae. They are not acanthine as in *Tryplasma*, but at the edge of the stereozone they are serrate as in *Disphyllum* {*Phacellophyllum*}. They are numerous, but cannot be counted owing to the metamorphism. The tabulae are thin, four in the space of 5 mm. They are either flat and complete or slightly domed and extending halfway across the tabularium. In one part of the vertical section there are seen to be three rows of dissepiments. They are rather small; the outer two rows are concave towards the axis, but the inner series is of horse-shoe plates, globose distally.

Remarks.—The dissepiments and the type of septa indicate that this species belongs to the genus *Disphyllum* and not to the genus *Amplexus*, which has no dissepiments, nor to the genus *Tryplasma*, which has acanthine septa and no dissepiments. The species is very close to *D. geinitzi* Lang and Smith, from the Middle Devonian of Bensberg, near Cologne, Germany, but differs in that the septa are so dilated as to form a peripheral stereozone.

Text-fig. 1.—*Amygdalophyllum thomsoni* (de Koninck); transverse section of neotype (S.M., A 6979*f*), Lower Carboniferous, Colocolo, New South Wales. × 2 diameters. The drawing does not show sufficiently well that dilatation of the septa is greatest in the tabularium.

Text-fig. 2.—The same. Vertical section (S.M., A 6979*e*), of columella; the coral was too much crushed for a drawing to be made of the dissepiments and tabulae. × 2.

Text-fig. 3.—The same. Vertical section of topotype (S.M., A 6981*f*), showing portions of dissepimentarium and tabularium. The corallum was much crushed. × 2.

Text-fig. 4.—The same. Transverse section (S.M., A 6980*g*) of the columella of a topotype, showing included tabellae. × 2.

Text-fig. 5.—The same. Transverse section (S.M., A 6982*c*, crushed) of topotype in brephic stage, showing the dilated septa. × 2.

Text-fig. 6.—*Disphyllum arundinaceum* (Lonsdale). Transverse section of holotype (B.M., 31070). [Middle Devonian], Barber's [Creek], Shoalhaven [River], New South Wales. The specimen is much recrystallized. × 2.

Text-fig. 7.—The same. Vertical section of holotype (B.M., 31070). × 2.

Text-fig. 8.—*Euryphyllum ? australis* (M'Coy). Oblique natural section of holotype (S.M., A 8002). [? Permian] Calcareous shale of Wagamee, New South Wales. Natural size.

Text-fig. 9.—*Tryplasma dendroidea* Etheridge. External view of S.M., A 8000, referred by M'Coy to *Amplexus arundinaceus* Lonsdale, from the [Silurian or Lower Devonian] grey limestone of Curradulla or Limestone Creek [Yass District], New South Wales. Natural size. The three large corallites are offsets from the fourth.

Genus *Euryphyllum* Hill.

Genotype.—Euryphyllum reidi sp. nov.,[1] Permian, Upper Dilly stage, Cabbage Creek, Springsure District, Queensland.

Diagnosis.—Simple, almost erect turbinate to ceratoid Rugose corals with well-marked interseptal ridges, and major septa grouped about a narrow closed cardinal fossula, dilated and laterally contiguous except in a zone of variable width midway between the periphery and the axis; very short minor septa appear late, and remain buried in a peripheral stereozone. Tabulae are distant, usually much dilated, complete or incomplete, and inclined from the axis to the periphery. There are no dissepiments.

Remarks.—The genus is known only from the Permian of Australia, New Zealand, Timor, and Russia.

Euryphyllum (?) *australis* (M'Coy).

(Text-fig. 8.)

Strombodes ? australis M'Coy, 1847, p. 227, pl. xi, fig. 9, from the calcareous [? Permian] shale of Wagamee, New South Wales.

Lonsdaleia australis (M'Coy); Etheridge, 1878, p. 37.

Strombodes ? australis M'Coy; Etheridge, 1891, p. 7.

Holotype (by monotypy).—S.M., A 8002, figured M'Coy, loc. cit.

Diagnosis.—Like large *Euryphyllum*, with septa convex to the fossula, a short cardinal septum, and numerous undilated tent-shaped tabulae.

Description.—The only specimen is a fragment, 30 × 30 mm., of a large, simple, trochoid corallum, which was probably slightly curved. The base of the fragment is an oblique fracture just below the calice, 17 mm. in diameter, and the top is a section through the compressed and rather crushed calice, which was probably half as deep as the length of the complete corallum. The epitheca is destroyed, or covered with a limonitic deposit.

There are thirty-seven major septa; minor septa are not seen in either the calical section or the basal section, but they must be present, for the number of septal bases exposed by the weathering of the periphery is twice the number of major septa. The bases of the septa are much dilated, forming a peripheral stereozone 2–3 mm. wide. The axial ends of the major septa curve and run together to close the fossula, and to build up by their amalgamation a U-shaped axial structure. The curvature is convex to the cardinal septum. The fossula, which is on the shortest side of the corallum, is rather narrow, extends just beyond the axis, expands slightly towards the axis, and contains a short cardinal septum.

The alar fossulae are not pronounced. There are eight or nine septa in each quadrant. Tabulae are numerous, undilated, and conical.

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[1] The genotype is being described and figured in *Proc. Roy. Soc. Queensland* (1937), where the relations of the genus to other zaphrentoids are discussed.

Remarks.—The young stages and limits of variation of the species and the geographical position of its type locality, " Wagamee," are unknown. The fragmentary monotype is closer to the Permian *Euryphyllum* than to any other zaphrentoid genus, but I refer it to this genus with some doubt. The longitudinal ridges observed by M'Coy are merely the bases of the septa exposed by weathering. M'Coy remarked that " it is certainly without transverse chambers ", but numerous tabulae can be seen in the oblique section.

It is possible that the species described by Etheridge, 1891 (p. 14, pl. x, figs. 1–3), as *Zaphrentis robusta* de Koninck from the [Permian] Upper Marine of Branxton, on the Hunter River, and near Dee's Hotel, West Maitland, New South Wales, belong to this species, but I have not seen Etheridge's specimens. It is scarcely possible that Etheridge's specimens could belong to de Koninck's species, which was from the Lower Carboniferous (Burindi) of Burragood, on the Paterson River, and was much smaller.

Genus *Tryplasma* Lonsdale.

Tryplasma Lonsdale, 1845, p. 613.
Tryplasma ; Lang and Smith, 1927, p. 461.
Tryplasma ; Hill, 1936, p. 204.

Genolectotype.—*Tryplasma aequabile* Lonsdale ; see Lang and Smith, 1927, p. 461.

Diagnosis.—Simple or fasciculate Rugose corals with rhabdacanthine or holacanthine septa (see Hill, loc. cit.), a peripheral stereozone, complete tabulae, and no dissepiments.

Remarks.—The genus is common in the Silurian of Europe, and is probably represented in the Silurian of America by the genus *Pycnostylus* Whiteaves. It also occurs in the Lower Devonian of Graz, Austria, where it has been called *Spiniferina* Penecke.

Tryplasma dendroidea Etheridge.

(Text-fig. 9.)

Tryplasma dendroidea Etheridge, 1907, p. 87, pl. xiv, fig. 1 ; pl. xv, fig. 5 ; pl. xviii, figs. 2–6 ; pl. xix, fig. 6 ; pl. xxii, figs. 11–15 ; pl. xxiii, fig. 9 ; pl. xxiv, fig. 6 ; pl. xxvii, figs. 3 and 4 ; from the Silurian [or perhaps Lower Devonian] of Derrengullen Creek, a branch of the Yass River, New South Wales, and of Barber's Creek, a branch of Derrengullen Creek.

Amplexus arundinaceus Lonsdale ; M'Coy, 1847, p. 228 [Silurian or Lower Devonian] " grey " limestone of Curradulla or Limestone Creek [Yass District], New South Wales, A 8000, Sedgwick Museum, Cambridge ; *non Amplexus arundinaceus* Lonsdale.

Type Material.—That from Derrengullen Creek is partly in the Mining and Geological Museum of Sydney, and partly in the Australian Museum, Sydney; that from Barber's Creek is in the Australian Museum.

Diagnosis.—Dendroid *Tryplasma*; the corallites are ceratoid and large with quadripartite axial increase; the offsets diverge and attain a diameter of from 12 to 20 mm.; all the septa are very short and rhabdacanthine; the tabulae are distant and complete.

Remarks.—M'Coy (1847, p. 228) referred a specimen (S.M., A 8000) belonging to this species to *Amplexus arundinaceus* Lonsdale, stating that it was " common in the gray limestone of Curradulla or Limestone Creek, New South Wales ". On the tablet in the Sedgwick Museum the age is given as Carboniferous; but this is wrong. The species occurs in beds at present referred to the Silurian. The " Limestone Creek " of M'Coy's label is probably that in the Yass District, near Bowning. Turreted gasteropods occur in the specimen.

Gen. et sp. indet.

S.M., A 8001 (= 1764 of W. B. Clarke Collection) was named by M'Coy (1847, p. 227) *Turbinolopsis bina* Lonsdale. The specimen is from the Lower Carboniferous (Burindi) shales of Dunvegan on the Paterson River, New South Wales, and does not belong to Lonsdale's Lower Silurian species. It is at present indeterminable, being an incomplete mould of a strongly curved ceratoid corallum and a cast of a calice. The corallum was 20 mm. in length, attained a maximum diameter of 8 mm., and appears to have had two rejuvenescence rims. It was probably rather crushed. Longitudinal and transverse striation of the epitheca are faintly marked. The cast of the calice shows that the latter had a steeply sloping peripheral platform 4 mm. long, and an axial pit 4 mm. wide, with possibly a low boss. The major septa extended to the boss, but the minor septa are only as long as the sloping peripheral platform. The grooves in the cast of the calice corresponding to the minor septa show small pointed hollows, each left by a trabecula forming a serration along the upper margin of the septum. At present no corals which could have left such a cast are known from the Lower Carboniferous of New South Wales.

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The Melton Mowbray Anticline.

By P. E. Kent, University College, Nottingham.

Introduction.

THE structure of the Jurassic area of north-east Leicestershire has been discussed by several writers, and markedly different opinions have been held. In the present paper fresh information about the variation of the Jurassic beds is brought forward to show the true position and orientation of the fold axes active in Jurassic times, and the history of the fold is discussed in more detail than has previously been attempted.

The Direction of the Axis.

The lack of information about the beds around Melton Mowbray, consequent upon a thick covering of drift and the featureless character of the Lower Lias clay country, makes it necessary to determine the orientation of the anticline partly from that of the associated syncline to the north. The accumulated evidence shows that a marked variation in thickness of certain formations takes place. The more important evidence which delineates the course of the axes is as follows.

A recent study has shown that the basal beds of the Lower Lias more than double in thickness from Plumtree Wolds to Normanton Hills, near East Leake, and that they attenuate again to Barrow-on-Soar, still farther south (see Fig. 1). The beds are tending to a maximum thickness along an E.–W. line passing through East Leake. Farther east bore-holes show that the Upper Lias is about 100 feet thick at Grantham, 225 feet thick at Buckminster, and maps show that it is about 120 feet thick near Market Overton, thickening again farther south. Finally, near and in the Fens, records show that the Great Oolite Series is very thick along an E.–W. line passing through Dunsby and Pinchbeck. Other formations show correspoding changes in thickness, although less detail is available. This evidence leads to the conclusion that a line through East Leake, Waltham, and Dunsby marked the centre of a Jurassic syncline, which extended in a direction almost precisely E.–W. It has previously been shown by Cox that the associated anticline passed a little to the south of Melton Mowbray, and the stratigraphical evidence shows further that it lay near Market Overton and Clipsham, and thus also had an E.–W. orientation.

On the line of the anticline a little to the west is Charnwood, which, as previous writers have suggested, owes part of its elevation and the south-easterly pitch of the axis to a cross fold. This E.–W. anticline would be in the right position to produce this effect. North of Charnwood lies a broad trough of Mesozoic rocks which presumably represents the continuation of the syncline just shown to exist farther east.

Several miles to the west extensive outliers of Rhaetic in Needwood Forest may indicate the continuation of the syncline beyond the belt of Palaeozoic rocks brought up by the Charnwood anticline.

The orientation of the anticline and syncline thus demonstrated from the variations of the beds disagrees with that described by previous writers.

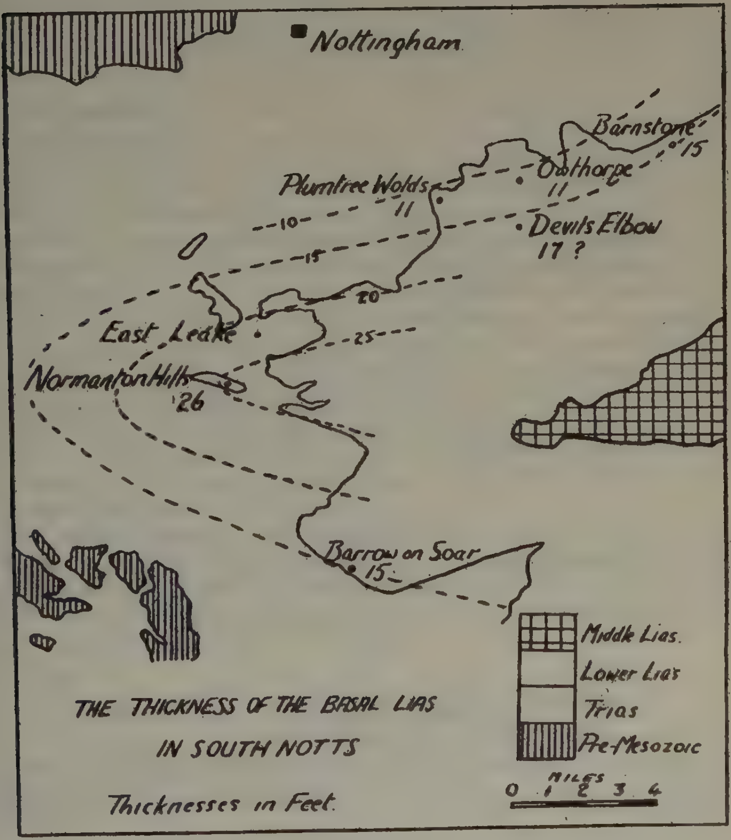

FIG. 1.

With the views of Professor Cox (1919) the writer is, in general, in agreement. Professor Cox ascribed an E.–W. direction to the anticline, and suggested that it was partly responsible for the uplift of Charnwood. In the latter part of the paper, however, he clearly stated that the anticline continued parallel to the Rempstone fault, which curves round towards the north-west. If this were so, the anticline would be in close proximity to Normanton Hills, where the Lower Lias is at its thickest, and would, moreover, lie parallel to the Charnwood anticline. In the later paper he and Trueman merely refer to the anticline as E.–W., which is the present interpretation (1920).

Dr. Rastall (1927) held that the line of the syncline of Cox and Trueman was indicated by the westwardly projecting tongues of the Jurassic beds to lie E.N.E.–W.S.W., and that the anticline had a similar orientation. This is at variance with the stratigraphical evidence adduced above, for his syncline would not pass near the area where the Lower Lias is thick, and his anticline would pass near Buckminster, where the Upper Lias is at its thickest, and cross the area where the Inferior Oolite is well developed. Dr. Rastall's suggestion that the E.N.E.–W.S.W. anticline was responsible for

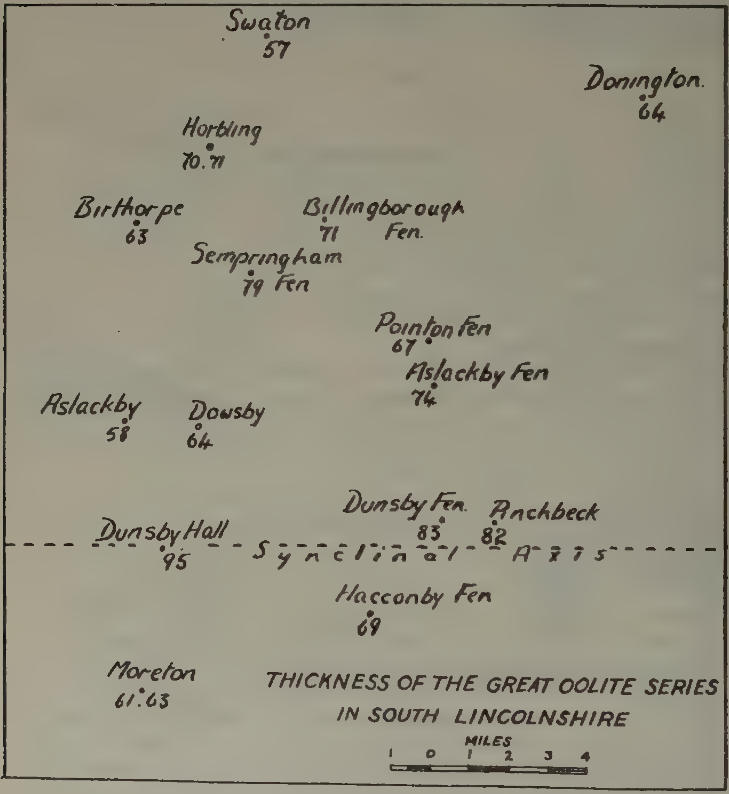

Fig. 2.

the uplift of Charnwood cannot be accepted, for Charnwood would be in line with the syncline.

Examination of the 1 in. map (Sheet 142) shows that the projecting outcrops are undoubtedly synclinal, so that this must be another structural axis. At Barrow-on-Soar the Lias dips down to the level of the Soar alluvium; at Holwell the observed dips indicate a syncline; at Waltham the tongue of Lincolnshire Limestone suggests a syncline; and the gentle down-fold between Boothby Pagnell and Burton Coggles suggests a further continuation. The synclinal axis would thus curve from E.–W. in the east to N.E.–S.W. in the west. It may be, however, that this is not due to a single fold.

Since this syncline was not active in Jurassic times, it is of interest to inquire how and when it was formed. It is significant that away from the centre of the Jurassic syncline the beds tend to have a N.E.–S.W. strike. This may be seen south-west of Old Dalby, from Eastwell to Belvoir and from Branston to Grantham. The inference is that the modern lie of the beds is the resultant of the intersection of later Caledonian and older Armorican folding. The local incidence of folds having this N.E.–S.W. orientation is shown in the Vale of Belvoir. The 1 in. map shows that along a line from Nether Broughton through Plungar, Allington, and Hough-on-the-Hill the beds have a persistent Caledonian strike, and at Stathern Station and Allington (Jukes-Browne, 1885, figs. 4 and 5) and Hough this is closely connected with an anticline of similar strike which interrupts the prevalent dip of the beds. These Caledonian folds are evidently post-Jurassic and may be provisionally referred to the Tertiary.

To avoid confusion the E.–W. syncline active in Jurassic times will be called the Waltham syncline. Cox and Trueman used the name Old Dalby syncline, but as Old Dalby lies almost on the E.N.E.–W.S.W. axis, and away from the E.–W. fold, this name is not appropriate.

THE HISTORY OF THE FOLD.

The Melton Mowbray anticline and Waltham syncline had a long history, which can be examined in detail in the Triassic and Jurassic rocks.

If the main doming of Charnwood is to be ascribed to an earlier movement of this E.–W. anticline, the history of the axis would date back to pre-Triassic and probably pre-Palaeozoic times.

By Triassic times a depression had been produced north of Charnwood and the Ashby coalfield, for the Bunter is well developed near the Trent valley (200 feet around Repton) but is overlapped by the Waterstones in the south (near Ashby de la Zouch and Hartshorn). Professor Swinnerton has shown that at the beginning of Keuper times western waters entered the Nottingham basin "along a strait which lay between Charnwood and the Pennines" (1918, p. 28).

It was suggested by Cox and Trueman that the Rhaetic appeared to be slightly thicker in the Waltham syncline. The black shales measured 14 feet at Owthorpe and at Barnstone, but were 20 feet thick at East Leake (*Mem. Geol. Surv.*, Melton Mowbray, pp. 17, 104). The upper beds measured from 17 to 19 feet in the north, but the thickness at East Leake seems doubtful. I am informed by Mr. S. G. Clift that the road cutting 1 mile south of Bunny exposed 20 feet of grey beds resting on 20 feet of black shales. It is thus clear that the Rhaetic beds thicken from the north to the centre of the syncline, and a record of 16 feet of black shales at Melton Mowbray (loc. cit., p. 106) suggests a corresponding attenuation towards the south.

A detailed study of the Lower Lias of the region (by the writer) has recently shown that the lower beds thicken towards an E.–W. line through East Leake (Fig. 1). In addition, there is evidence that Charnwood and the Southern Pennines were land masses, separated by a bay or strait. The relative uplift of Charnwood and the sinking of the area to the north is to be ascribed to differential movement of the Melton Mowbray axis and Waltham syncline.

Exposures in the higher part of the Lower Lias are not sufficiently numerous to provide information about the behaviour of the axis, but the Middle Lias yields some evidence.

The presence of the *acutum* zone recorded by Trueman in the Waltham syncline at White Lodge (1 mile S.E. of Eastwell), and near Caythorpe (1918, p. 108) was purely tentative, being based on the presence of a thin unfossiliferous stratum between the Middle and Upper Lias at each locality. In later writings the doubtful character of the evidence has been overlooked, and the presence of the zone taken as established (Cox and Trueman, p. 201). The present writer is, however, able to confirm the presence of the zone at White Lodge as a result of the discovery of a specimen of *Dactylioceras cf. athleticum* 1 inch below the top of the Marlstone Ironstone. In addition, numerous crinoid ossicles were found in the top few inches of the bed, and as has been pointed out previously (A. R. Horwood, 1907, p. 402–3), a crinoid bed of similar character makes up the lower part of the *acutum* zone around Tilton and Billesdon, Leicestershire. The *acutum* zone is thus not represented by the thin white limestone band which rests unconformably upon the Middle Lias, but by the highest part of the Marlstone Ironstone.

More significant than the absence of the *acutum* zone over the anticlinal region, which was based on negative evidence, is the behaviour of the Marlstone itself. The bed may be as much as 40 feet thick between Holwell and Belvoir, and 18½ feet near Tilton, but is only 9 feet thick at Langham, in the intermediate area. The Marlstone Ironstone thus shows marked attenuation in the neighbourhood of the anticlinal axis.

Thickening of the Upper Lias in the Waltham syncline is shown by the record of 225 feet of that formation at Buckminster, compared with 100 feet at Grantham, and about 120 feet at Market Overton on the line of the Melton Mowbray anticline. It has been stated (Cox and Trueman, 1920, p. 202) that the *tenuicostatum* zone shows a slight thickening in the syncline, presumably as compared with Grantham, but as the junction of the Middle and Upper Lias has never been exposed at the latter place this must be taken as subject to confirmation.

The movements of the axis exercised considerable control over the deposition and pre-Bathonian erosion of the Inferior Oolite. An investigation of the Inferior Oolite is being carried out at the present time, and the results will be published in due course. It will suffice to say that several zones absent farther north and south are present in the Waltham syncline, and that the formation is abnormally thin on the line of the anticline. Thus the bed is about 100 feet thick between Ropsley and Ancaster, increases to 132 feet or more at Boothby Pagnell, is only 60 feet thick at Clipsham and 74 feet at Stamford.

The variation of the Great Oolite Series has never been used for determining the direction and position of axes, for although numerous records are available, it is not possible to rely on the classification of the beds by the borer. In Lincolnshire the series consists of Upper Estuarine Series, Great Oolite Limestone and Blisworth Clay, which form a conformable succession without clear lines of division. In borings, the top and bottom of the series are clearly demarcated by the Cornbrash and Lincolnshire limestone respectively, but oyster beds and sandstones in between may be grouped either with the clay beds or with the limestone by the sinker. This renders difficult any attempt to trace the lateral changes of any one member, but the sum of the thicknesses of the three parts of the series provides a reliable index of the variation in thickness, and thus of the tectonics controlling sedimentation. The appended map (Fig. 2) illustrates these changes in the area under consideration. At Dunsby and at Pinchbeck the beds are more than half as thick again as the normal measurement. This expansion is mainly due to the thickening of the clay members of the series in the syncline.

The Upper Cornbrash extends uniformly and with little change over this part of Lincolnshire, but the Lower Cornbrash is more restricted. The records of old sections, now obscure, in the memoirs of the Geological Survey show that characteristic fossiliferous Lower Cornbrash was exposed at Bitchfield, Edenham, Grimsthorpe and Lound. A disused pit at Skillington (6 miles south of Grantham) still shows the Upper and Lower Cornbrash, the latter yielding abundant *Pseudomonotis echinata*. Farther north (Threckingham, Quarrington and Sleaford) and south (Clipsham, Manthorpe, Casewick and Stamford) the fauna of the Upper Cornbrash only has been recorded, although in several cases the full thickness of the bed has been exposed. The localities where the Lower Cornbrash fauna has been recorded lie on, or close to, the axial line of the Waltham syncline, and it thus seems that the syncline subsided with relation to the Melton Mowbray anticline, and a more stable area to the north, during or immediately after the deposition of the Lower Cornbrash. In other parts of England the distribution and character of the Cornbrash bears little relationship to known anticlines, so that this is of particular interest.

CONCLUSIONS.

1. The anticlinal axis which passed immediately south of Melton Mowbray, and the associated syncline passing through Waltham, have an E.–W. orientation.

2. The Waltham syncline subsided with relation to the Melton Mowbray anticline repeatedly in Mesozoic times. The resulting variation in thickness can be traced in the Trias, Rhaetic, basal Lower Lias, Middle Lias, Upper Lias, Inferior Oolite, Great Oolite and Cornbrash.

3. The attenuation of the Jurassic beds north, as well as south, of the syncline suggests the presence of an E.–W. anticline passing through or near Grantham.

4. The synclinal tongues of the Jurassic beds in this area are partly determined by the presence of a Caledonian fold or folds of Tertiary (?) date.

I am indebted to Professor H. H. Swinnerton for reading the manuscript of this paper and for making valuable suggestions.

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On *Rhynchotreta cuneata* (Dalman) 1828, with a Diagnosis of the Genus *Rhynchotreta* Hall 1879.

By J. K. S. St. Joseph, Sedgwick Museum, Cambridge.

History and Introduction.

THE specific name of this form is not in doubt, but its authorship is less securely determined. The species *Terebratula cuneata* was proposed by both Dalman (1828, 141, Tab. vi, figs. 3*a–c*) and Hisinger (1828, 220, 239, Tab. vi, fig. 5) in the same year, and the first time each author mentions the name, he ascribes it to the other. Each account is accompanied by figures, and there appears to be no ruling of the International Commission on Nomenclature that would settle the authorship in such a case. Dalman's account, however, appears in the volume for 1827, though the title page bears the imprint 1828, and such a choice of authorship agrees with alphabetical priority and with the usage of most subsequent palaeontologists.

Dalman (1828, 141) refers to " Gottandia " as the area from which he obtained the species, while Hisinger (1828, 220, 239) mentions a Klinteberg horizon, and (with other names) Östergarn as a locality. Later (1837, 81) he gave Klinteberg as a locality and this place is also cited by Lindström (1861, 365, 381). As Östergarn is not on the outcrop of the *Klinteberg-kalkstein* as now understood, the Klinteberg area is probably the most precise locality it is now possible to fix, with the horizon somewhere in the Upper Wenlock.

The first real description of the form was by Hisinger (1837, 81, Tab. xxiii, figs. 5*a–c*), while Barrande (1847, 436–7, Tab. xvii, figs. 11*a–e*) gave a more detailed account of the Bohemian specimens; it was not, however, until Davidson's Monograph began to be published (1867, 164–6, plate, xxi, figs. 7–11) that a full treatment was attempted, and then only of the external characters.

The earlier authors referred the species either to *Terebratula* or *Atrypa*, but after 1859 it was referred consistently to *Rhynchonella*, until Hall (1879, 167–8) proposed the separation of certain Silurian species from that genus and their inclusion under a new genus *Rhynchotreta* for which he chose *Terebratula cuneata* Dalman as type. He also considered the American specimens to be varietally distinct and separated them as *R. cuneata* var. *americana*. Hall's original diagnosis of *Rhynchotreta* was partly mistaken, while his emended description does not closely agree with the characters of *T. cuneata* Dalm., which is the species he selected as genotype. A separation of *T. cuneata* Dalm. from the genus *Rhynchonella* Fischer emend. Hall and Clarke (1894) and Buckman (1914), is, however, justified, for the forms differ entirely in internal structure, and it is consequently necessary to give a new diagnosis of the genus *Rhynchotreta*. Though Davidson (1883, 152–3) preferred the retention of the older name, *Rhynchotreta* was adopted in current usage in America by Beecher and Clarke (1889, 47–51) and Hall and Clarke (1894, 186–7), the former studied the developmental changes in certain external characters, including the growth of the deltidium. Since then no systematic work has been done on the species, and there has been no detailed account of the internal structures.

MATERIAL.

There has been available for study a large number of British specimens mostly from localities on the various Silurian inliers in the Welsh borderland. The species is well represented in the Collections of the British Museum (Natural History), the Museum of the Geological Survey, the Sedgwick Museum, and the Birmingham University Museum. In all, the writer has examined between three and four hundred individuals. The preservation is very similar to that of *Camarotoechia borealis*,[1] and the description there given of the methods of study applies equally to this species, except that owing to its small size, drawings spaced at least at 0·075 mm. or 0·05 mm. intervals are usually necessary in investigating the internal structure. It has not been possible to determine which form in Dalman's collection was the original type, but a number of specimens from Klinteberg (Gotland) have been examined which have at least the value of topotype material. Specimens from Southern Norway, Bohemia, and representative specimens of *R. cuneata americana*, from New York in the British Museum (Natural History) have also been studied.

DIAGNOSIS.

Shell small, biconvex; outline acutely triangular. Always a little longer than wide (*vide* table of dimensions). The shell attains its greatest width anteriorly. Hinge-line curved. A median sinus in the ventral valve and corresponding fold in the dorsal. Surface of the valves folded into prominent, sub-angular, or rounded radiating plications. Ventral valve the higher, slightly less convex than the dorsal. Pedicle foramen apical. Delthyrium closed by deltidial plates which meet in the centre line. Dorsal umbo incurved. Dentition specialized; in the ventral valve strongly developed dental plates support thick teeth, which fit closely into sockets in the dorsal valve. In the dorsal valve a thickened hinge-plate supported on the inner surface of the valve wall, and carrying on its ventral surface the crural bases, which are separated by a deep groove. Crura short, simple, sub-parallel.

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[1] GEOL. MAG., LXXIV, 1937, p. 34.

DISCUSSION.

External Characters.

The relative proportions of length, breadth, and thickness vary in different individuals. In adult specimens the length is always a little greater than the breadth, and usually at least one and a half times the thickness. The greatest breadth and thickness is attained about two-thirds of the distance towards the anterior margin. The outline is always markedly triangular, the shell becoming acute posteriorly, the two lateral margins enclose at the ventral umbo an angle which is remarkably constant, and of about 70 to 75°. The lateral profile is subtriangular, biconvex, the dorsal valve having a greater curvature than the ventral. The anterior surface is flattened; in each valve the extreme anterior part may be bent almost at right angles to the rest of the shell.

The shell is relatively thin. In the specimens that have been examined it consists of a single layer, though a very fine outer layer may possibly have been lost. There is frequently a certain amount of internal thickening in the posterior region of the valves, but this is composed of material in continuity with the main shell layer.

The ventral sinus and dorsal fold are usually prominent; occasionally they may be poorly developed. The sinus is gently concave; it increases in width anteriorly, and near the margin may have straight sloping sides. At the anterior margin it projects as a slight tongue into the fold of the dorsal valve. The fold is almost exactly the counterpart of the sinus. A notable feature, and one that has been discussed on more than one occasion, is the inversion of the fold and sinus (Beecher and Clarke, 1889, 47–51, Hall and Clarke, 1894, 136–7). In the adult, a low median fold commences almost at the umbo of the ventral valve, and increases slightly in width anteriorly. About half way towards the anterior border the surface is depressed so that the convexity first becomes flattened, and then a shallow sinus develops. In the dorsal valve, a narrow depression commences at the umbo and soon develops in a similar fashion into a fold. Though the initial sinus is usually slight and shallow, in some individuals it may be quite prominent. As a result of this inversion, cross-sections of the shell show posteriorly a ventral fold and dorsal sinus (cf. Figures, 2, 3, and 5), while farther anteriorly the reverse obtains. For a short distance, too, below the hinge line, the lateral margins of the valves meet each other almost in the same plane, so that cross-sections of the valve present a markedly sub-rectangular appearance.

Except for a small oval area at each lateral margin of the shell, the whole of the surface of the valve is folded into sub-angular or rounded plications. These commence at or near the umbones and increase in width towards the anterior margin. It is only rarely that new plications arise by bifurcation. The interspaces, which are of the same width as the plications, are concave. Normally

4 to 5 plications lie within the limits of the fold and 3 to 4 within the sinus, and there is nearly always one more on the fold than within the sinus; when four plications compose the fold the two centre plications often have considerably the greater elevation. At the anterior margin there are from 9 to 13 plications in each valve, in different individuals. On the interior the plications appear as grooves, as if the shell surface had been sharply folded. Concentric raised lines or ridges are present and in well preserved material (quite unexfoliated) they may be prominent.

In each valve, the umbo is distinctly acute (Figs. 1 and 4). In the ventral valve, the apex is perforated by a sub-circular pedicle foramen. The triangular delthyrium is closed by two small, prominent, slightly convex deltidial plates, which join in close suture along the median line. These plates may be seen in suitably preserved specimens to be crossed by oblique growth-lines. Anteriorly, the delthyrium is bounded by the dorsal umbo, which is closely incurved.

ARTICULATION.

The articulation is specialized. In the ventral valve, blunt, slightly divergent, elongate teeth, occur near the margins of the valve, somewhat below the delthyrium. They are supported on well developed dental plates (Figs. 1, 2, 3, and 5). The teeth fit closely into sockets at the sides of the hinge-plate of the dorsal valve, outside the crural bases. The outer margin of the sockets is formed by the edge of the valve, the inner margin by the thickened side of the hinge-plate. During growth, the teeth appear to have moved somewhat anteriorly, and the track of the teeth is represented by a continuation posteriorly of the dental plates. In the dorsal valve the posterior continuations of the sockets, that were no longer functional, usually became partially filled in the adult with a callus-like deposit of shell material. Owing to the inward curve of the teeth and the very exact fit between tooth and socket, the amount of movement possible between the valves must have been very slight, while it is frequently impossible to separate the two valves without distorting or fracturing the dentition.

INTERNAL CHARACTERS.

Ventral Valve.

In the ventral valve (Fig. 1) the dental plates are prominent, and form a rigid support for the teeth. They commence just below the umbo (Figs. 2 and 3) and continue anteriorly, slightly divergent. They arise almost at right angles from the back of the valve, and divide the posterior portion of the valve into a central chamber and two narrow lateral cavities. In different individuals these cavities may be filled with a variable amount of shell thickening, which is developed especially just below the teeth. The dental plates may extend for a short distance anterior to the teeth, or be continued as small ridges on the interior of the valve, but they usually curve sharply back to join the inner surface of the valve wall.

The development of the dental plates is disclosed by a study of serial transfers. These reveal that the plates arise almost at the apex of the valve (cf. Fig. 3, sections 4–10), by an inward arching of the growth-layers of the valve wall. The junctions between the plates and the valve wall lie at the margins of the incipient fold in this valve, the line of the plates being continued to the anterior margin by the direction of the sides of the sinus. In casts, the position of the plates is revealed by two slightly divergent furrows.

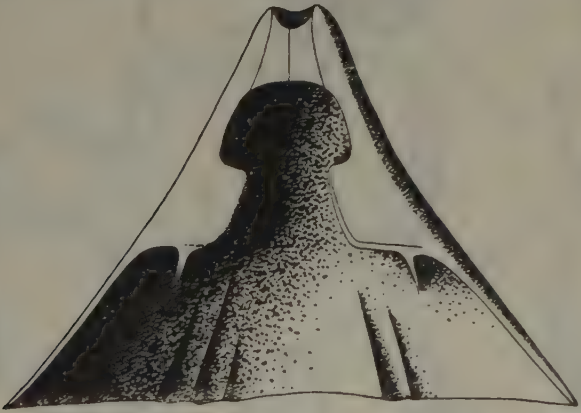

Fig. 1.—*Rhynchotreta cuneata* (Dalman). Posterior portion of ventral valve, drawn from a wax model (Sedgwick Museum A 8997) of a specimen from the "Wenlock Limestone" of Dudley. × 10.

Dorsal Valve.

The umbo of the dorsal valve is usually incurved, so as to be hidden beneath the delthyrium of the ventral valve. From the umbo, a curved hinge-plate extends anteriorly. The hinge-plate (Fig. 4) is in two halves, inclined to one another, and carrying on their upper surface the crural bases. Laterally, each half of the hinge-plate is supported from the valve margin, while centrally it rests on the inner surface of the valve wall, which is there infolded in conformity with the external sinus. On either side of this central fold, two cavities extend posteriorly beneath the hinge-plate. The deposition of secondary shell thickening may enhance the prominence of the fold as well as fill the cavities below the hinge-plate, but in the specimens that have been examined the hinge-plate is

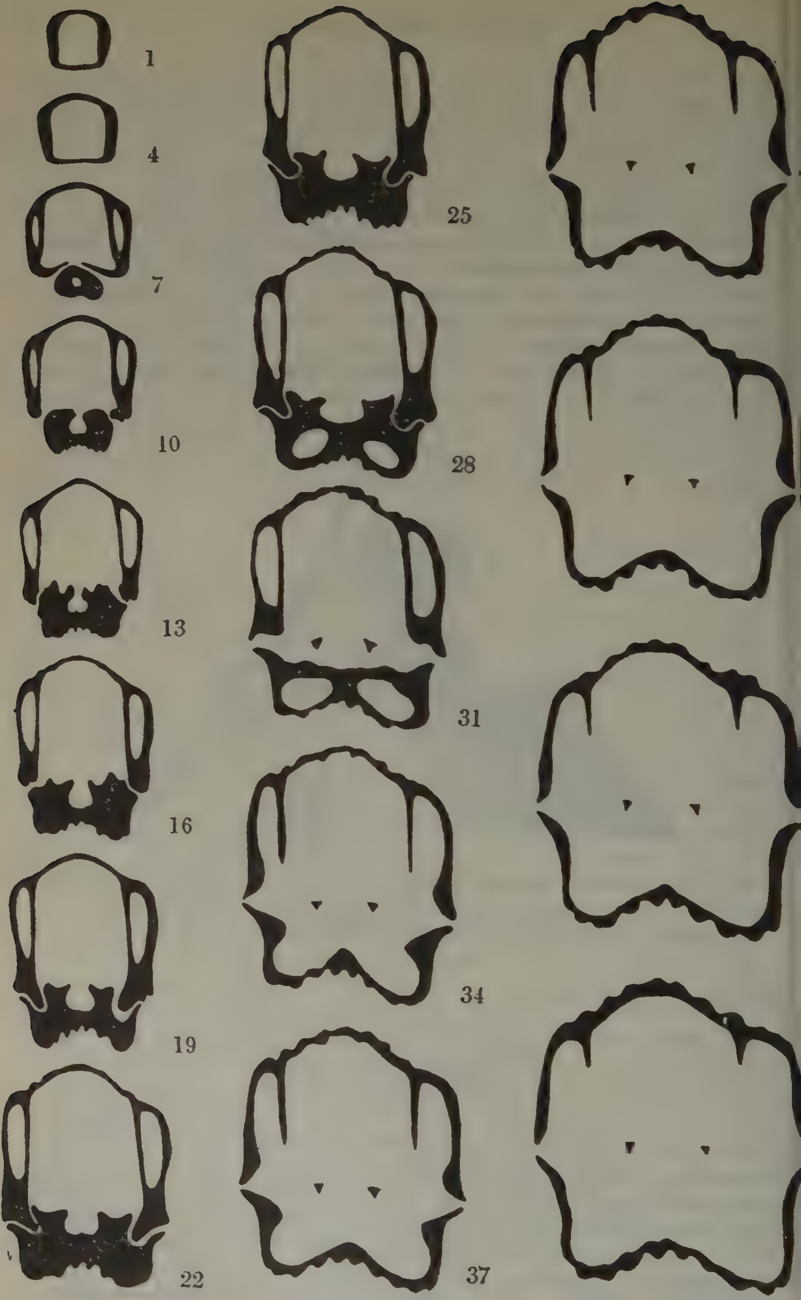

FIG. 2.—*Rhynchotreta cuneata* (Dalman). Serial sections through the posterior end of specimen, Sedgwick Museum A 8737, at 0·05 mm. intervals. × 8. Sections 1–49 (cf. Figs. 1 and 4).

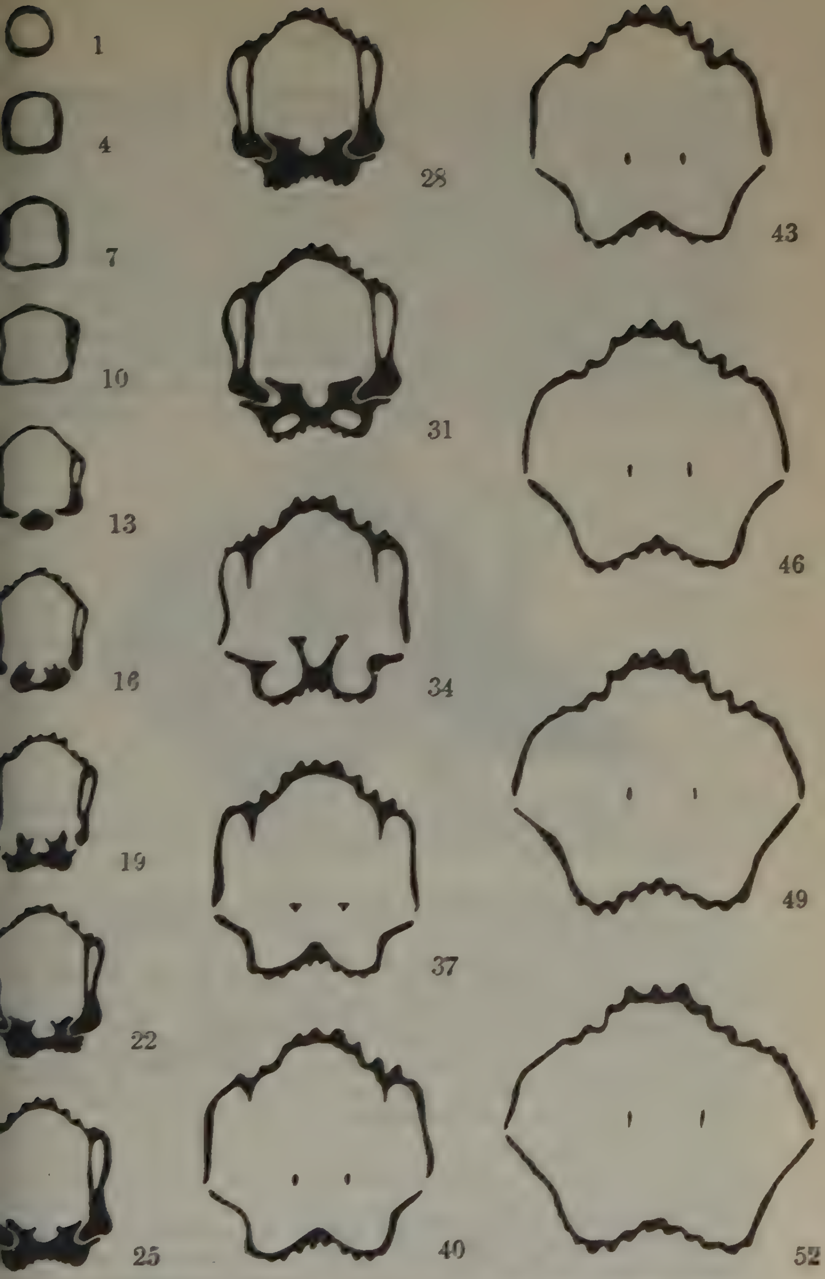

FIG. 3.—*Rhynchotreta cuneata* (Dalman). Serial sections through the posterior end of specimen, Sedgwick Museum A 5967, at 0·075 mm. intervals. × 6. Sections 1-52 (cf. Figs. 1 and 4).

hardly ever raised above the inner dorsal fold, though a low median "septum" may extend a short distance anteriorly. The outer edge of the hinge-plate is slightly raised, where it forms the inner socket wall.

The crural bases lie centrally on the upper surface of the hinge plate, with which they are fused. Commencing at the umbo, they diverge slightly anteriorly, defining the sides of a deep, elongate chamber, and continuing as short free crura (Fig. 4). This central chamber is not homologous with the crural cavity of *C. borealis*, for the latter is enclosed within the two branches of a median septum, a structural feature that does not occur in *R. cuneata*. The crura are relatively short, they normally extend only for a third or a quarter of the length of the shell. They consist of sub-parallel, simple, slender rods, oval or triangular in section and sometimes flattened on their ventral surfaces. They curve forward towards the ventral valve (Fig. 5). In all the specimens that have been examined there is no cardinal process.

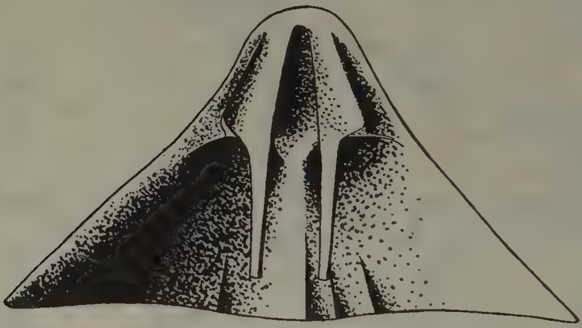

FIG. 4.—*Rhynchotreta cuneata* (Dalman). Posterior portion of dorsal valve, drawn from wax models (Sedgwick Museum A 8997) of a specimen from the "Wenlock Limestone" of Dudley. × 10.

In casts, a short, shallow groove (this never forms a deep furrow) marks the position of the median fold. Two slight projections form the infilling of the cavities below the hinge-plate, while a median elongate elevation marks the position of the central chamber. The positions of the crura are indicated by two small holes.

MUSCULATURE.

The impressions of the muscles and of other soft parts on the inner surface of the shell wall are usually shallow and not very clearly defined. In the ventral valve the muscle impressions were situated in the median plane, between the anterior portions of the dental plates. They are separable into a small deep central impression, marking the area of attachment of the fused adductor muscles, and the two lateral impressions of the divaricators. In casts of *Rhynchotreta cuneata* var. *americana* the muscle impressions are sometimes more distinct, as Hall and Clarke's figures show. A small amount of supplementary shell material may be present round the muscle scars, as has also been noted in other forms. In the dorsal valve, the divaricator muscles must have been attached posterior to the sockets, and were almost certainly bedded within the apical end of the rostral chamber, an arrangement analogous to that already described in *Camarotoechia borealis*. Slight impressions on the median fold below the hinge-plate probably mark the points of attachment of the adductor muscles and as shown in Fig. 5 the relative position of the crura and the dental plates, when the valves are in apposition, strongly suggests that the adductor muscles passed below, and partly between the former

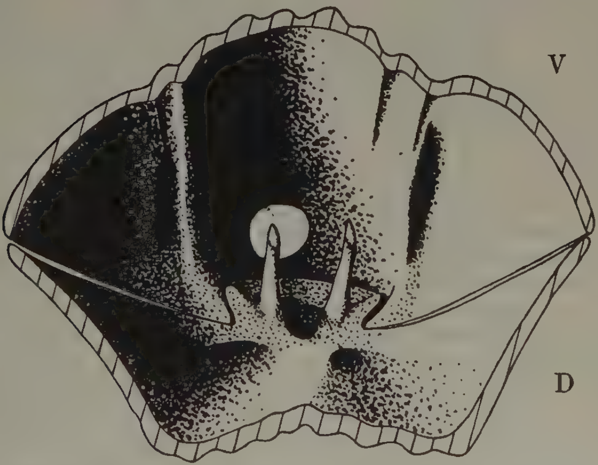

Fig. 5.—*Rhynchotreta cuneata* (Dalman). Posterior portion of the shell showing the two valves in apposition. × 10. (Cf. Figs. 1 and 4.)

DEVELOPMENT.

The development of certain external characters, outline and profile, growth of fold and sinus, the surface ornament, and the deltidial plates, has been studied by Beecher and Clarke (1889) with particular reference to American specimens. Their description is largely applicable to British material, and only a few additional observations are noted here.

Great care is necessary in discriminating between the different Silurian Rhynchonellids in their youngest stages, as in the earliest growth stages (2 mm. and less) of many forms there is a general similarity of outline and profile. *Rhynchotreta cuneata* (Dalm.) may however be distinguished from *Camarotoechia borealis* (v. Buch) and from most other British silurian Rhynchonellids by its greater triangularity of outline even in the young state, and by its inversion of fold and sinus.

Specimens from about 2 mm. in length upwards have been examined. In the smallest specimens the outline is ovate, the umbones breaking the line of the oval on the posterior side. The length is a little greater than the breadth; the profile is rather flattened; the ventral umbo is only slightly higher than the dorsal.

With growth, the length increases relative to the breadth, the ventral umbo increases in height and attains greater prominence, and the triangularity becomes more pronounced. At a length of 4–5 mm. the full number of ribs is usually attained. The concentric striae have been noticed on shells from 3 mm. in length upwards; in the youngest stages, they are exceedingly fine or absent.

From the earliest stage observed until the shell has attained a length of 4–5 mm., there is a slight median fold in the ventral valve and a shallow sinus in the dorsal. The anterior margin is thus convex to the ventral side. With further growth, the ventral fold is first flattened and then develops into a sinus, while the dorsal sinus changes similarly into a fold. Thus, from a length of about 8–9 mm. onwards the anterior margin is concave to the ventral side. A complete series of stages has been figured by Beecher and Clarke. It has already been noted that the record of this developmental change is retained permanently on the adult shell.

The delthyrium at first extends as a triangular opening from the apex of the ventral valve down to the level of the incurved dorsal umbo. When the individual has attained a length of about 5 mm., two small triangular deltidial plates appear at the lower corners of the delthyrium. With growth they approach one another and eventually unite in the median line just above the dorsal umbo. In the adult, they cover the entire delthyrium, apart from a subcircular pedicle foramen.

TYPES.

Dalman's collection is now in the Naturhistoriska Riksmuseum, Stockholm, where through the kindness of Dr. Hägg the writer was permitted to examine the material. There are many specimens of *Rhynchotreta cuneata* in the collection, for which the locality is given as Gotland, but no types are specified as such, nor is it now possible to determine the original of Dalman's figures. In view of this uncertainty, it is desirable to define new types. Four specimens (Sedgwick Museum, A 8778–8781, Fig. 6) from Klinte, Gotland, presented by Dr. Lindström to the Woodwardian Museum, have at least the value of chorotypes if not strictly topotypes (cf. discussion as to the original locality, in the "Introduction"), and are here chosen as neotypes of *Rhynchotreta cuneata* (Dalman). One of these specimens (A 8780) has been partially destroyed in the preparation of a set of serial transfers, which reveal the close resemblance in internal, as in external, characters, between individuals from the type area and British material commonly referred to *R. cuneata*, and with the American *R. cuneata americana*.

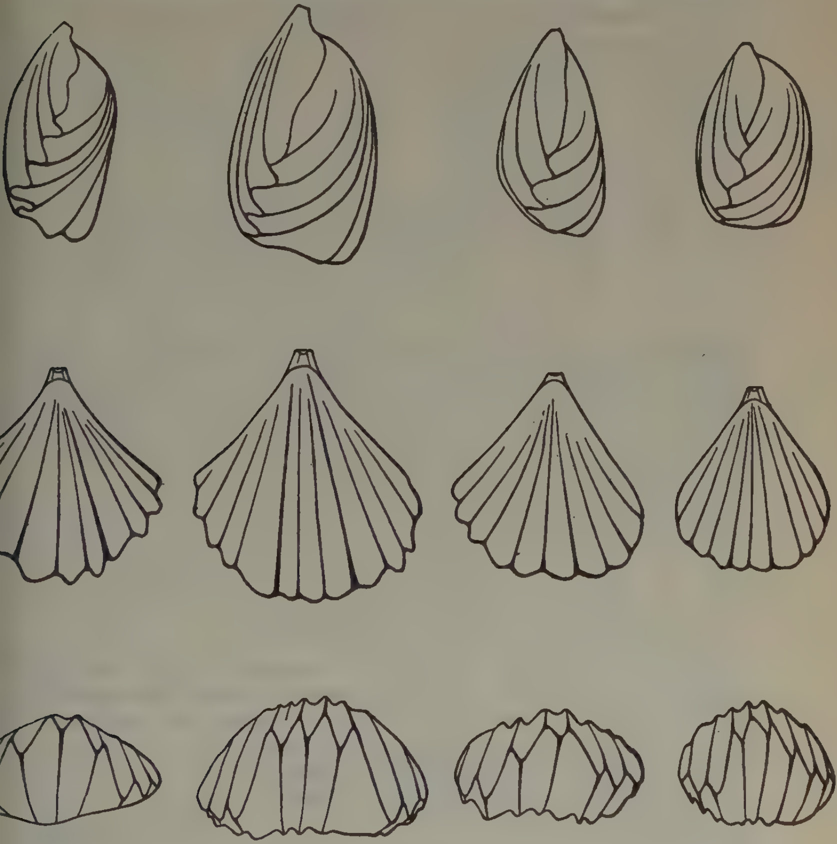

Fig. 6.—Right lateral (A), Dorsal (B), and Anterior (C) views of the four neotypes of *Rhynchotreta cuneata* (Dalman). From left to right S.M., A 8778–A 8781 respectively. × 2.

The four specimens are perhaps of rather less than normal size, but otherwise show an average development of those characters typical of the species. Their dimensions are given below. In each, the dorsal valve is considerably the more convex, the ventral umbo is high with an apical foramen, and a delthyrium closed by deltidial plates. The posterior inversion of fold and sinus is noticeable, while at the anterior margin the fold is in general moderately elevated. Nine or ten plications are present on the surface of each valve, of which four (A 8778–9) or three (A 8780–1) compose the fold, while three or two lie within the sinus. The surface of the valve is covered by fine thread-like lines.

DIMENSIONS OF TYPICAL SPECIMENS (IN MILLIMETRES).

Length.	*Breadth.*	*Thickness.*	
18·2	15·0	9·8	
17·5	16·7	10·1	
16·1	14·7	9·4	
13·9	12·8	8·9	
12·7	12·3	8·4	
11·1	10·0	6·8	
13·6	13·3	7·2	Neotype 1 (Sedgwick Museum A 8778)
16·7	15·3	9·4	Neotype 2 (Sedgwick Museum A 8779)
13·4	12·9	7·0	Neotype 3 (Sedgwick Museum A 8780)
11·7	10·1	7·6	Neotype 4 (Sedgwick Museum A 8781)

DISTRIBUTION AND VARIATION.

Rhynchotreta cuneata (Dalman) and its varieties are very common fossils in the shelly facies of the Silurian of Great Britain, Scandinavia, and America. In Britain further work is necessary before it will be possible to discuss the distribution of this species in space, but it appears to range from Llandovery to Wenlock horizons and its main area of occurrence is that of the Silurian rocks of the Welsh borderland, where its presence has been reported at a number of localities in several recent papers. It was not recorded from South Wales in the Survey Memoirs; in North Wales, Salter (1881, 431, 436, 459) reported it from Wenlock horizons. Its occurrence in Southern Scotland is doubtful, but it seems probable that it occurs in the west of Ireland.

The writer has himself collected the species from the Wenlock Limestone of May Hill, the Wenlock Shale and Limestone of Malvern, and the Wenlock Limestone of Dudley and Shropshire. The Wenlock Shale and Limestone are certainly the horizons at which it is commonest and most widely distributed.

In Southern Norway, Kiaer (1908 *passim*) recorded the species from stages 5 and 7–9. In Gotland, the type area, its presence was noted by many early authors (cf. " Introduction ") and has been confirmed by recent writers (Munthe, 1925, 14–20), while what was considered to be the same form has been reported from the Russian and Esthonian Silurian (horizon I; cf. Teichert, 1928, 65–6). In America the occurrence of *Rhynchotreta cuneata* was first noted in New York by Hall (1843, plate 13 (*sic*), figs. 3 and 4), who later separated the American specimens as a variety *Rhynchoteta cuneata* var. *americana*, a usage generally adopted by subsequent writers. The range of this variety is given by Bassler (1915, 1126–7) as the Niagaran of New York, Indiana, Ontario, etc.

A comparison of British material with specimens from the type area in Gotland shows that there is practically the same range of variation in each case. While this appears to hold true for this species in north-west Europe generally, the American specimens have been described as a distinct variety, raised by some authors to specific rank. The differences between American and British material do appear to justify a varietal separation. The rate of widening of the shell in *Rhynchotreta cuneata* var. *americana* is greater than in the typical *R. cuneata*; the lateral margins of the former are slightly concave and the outline has less of the sharply triangular appearance of British specimens. The American variety, too, has typically two or three fewer plications on each valve, and one fewer within the fold and sinus. The average size of the adult may be a little less, while the prominence of the fine concentric striae appears to be rather greater though this may depend on the preservation. The differences are readily appreciated by comparing Hall and Clarke's figures (1894, plate lvi, esp. figs. 31–4) with British specimens.

Until further species belonging to more genera have been described in detail, it is impossible to discuss the systematic affinities of *R. cuneata*, but the many points of difference between it and *C. borealis* may be noticed. There is a different arrangement of the dentition in the two forms, while the small dental plates in *C. borealis*, the dorsal septum supporting the crural cavity with its median process, and the small deltidial plates so contrast with the well developed dental plates, the sessile hinge-plate, and the prominent deltidium of *R. cuneata* as to preclude any possibility of close relationship between the two forms.

Rhynchotreta Hall, 1879.

Genotype.

Terebratula cuneata Dalman, 1828, *K. svenska Vetensk Akad. Handl.*, (for 1827), 141, Tab. vi, figs. *3a–c*.

In the discussion of the synonymy of *Rhynchotreta cuneata* (Dalman), mention was made of Hall's proposal (*28th Rep. N.Y. St. Mus.*, 1879, 167–8) of the genus *Rhynchotreta* as a subdivision of *Rhynchonella* Fischer (*sensu lato*). Since Hall chose *Terebratula cuneata* Dalman, as the type for *Rhynchotreta*, a description of the latter genus must be based on the characters of this species. Hall's original description of *Rhynchotreta* was partly erroneous (as he himself, 1894, p. 186, footnote, pointed out), while the examination of the type species undertaken by the writer has revealed that even his revised description (1894) is not wholly applicable as regards characters of generic rank.

The present redefinition of the genus is based on material from the type area of Gotland in the Naturhistoriska Riksmuseum, Stockholm, and the British Museum (Natural History), and especially on the four specimens (A 8778–8781) from Klinte, Gotland in the Sedgwick Museum (cf. p. 170). These specimens have been designated (p. 171) as neotypes of *Rhynchotreta cuneata* (Dalman), and consequently they also become genoneotypes of *Rhynchotreta*, by virtue of Hall's choice (Hall, 1879, 167–8) of this species as the genotype.

Hall's original description was as follows:—

"Shell triangular, surface with angular plications, ventral beak straight produced beyond the dorsal beak, extremity perforate, the foramen with an elevated margin; space between the foramen and hinge-line occupied by a deltidium in two pieces, being divided by a longitudinal suture, and transversely striated. Valves articulated by two slender curving teeth, proceeding from a broad curving hinge-plate in the ventral valve, which fit into corresponding sockets in the dorsal valve. Crurae rising from near the dorsal beak and curving into the ventral cavity, and thence recurved towards the dorsal side, and probably uniting. . . . Structure fibrous and apparently very minutely punctate." (Hall, *28th Rep. N.Y. St. Mus.*, 1879, 167–8.)

In the discussion of the Palaeozoic Brachiopoda in the "Palaeontology of New York", he gave the following revised description:—

"Elongate triangular, strongly plicated shells with fold and sinus normal, in adolescent and mature stages; long and broad cardinal slopes; beak erect, acuminate and produced on the pedicle valve. Foramen at maturity apical, its upper margin encroaching on the substance of the valve. Deltidium very conspicuous, convex, the component plates, in their late development, being anchylosed along the median suture. Dental lamellae vertical, resting on the bottom of the valve and enclosing a deeply impressed muscular scar; diductor scars elongate-flabelliform, divided by oblique ridges into anterior and posterior members; adductor impression central, elongate, and very small. The brachial valve bears a median septum which extends for one-half the length of the shell; being divided towards its posterior extremity, each branch supporting one process of the divided hinge-plate. The crura are long, slightly curved and somewhat expanded at their tips; between these there is a small, simple, cardinal process.

"External surface covered with exceedingly fine, filiform, papillose, concentric lines. Shell-substance fibrous, impunctate." (Hall and Clarke, *Palaeontology of N.Y.*, viii, part ii, 1894, 185–6.)

This is not wholly applicable either to specimens from the type locality, nor to British material, for its differs in certain points of fact. In the true *Rhynchotreta cuneata* (Dalman) the median "septum" in the dorsal valve is usually small and is due rather to the deposition of supplementary material on the inner surface of the fold than to the presence of a distinct septal plate. In Scandinavian and British specimens the muscle scars are normally but faintly marked, and even in casts may be distinguished only with difficulty. In the specimens that have been examined no cardinal process has been noticed and the crura never attain to half the length of the shell, while the slight expansion of the crural extremities which occurs in *C. borealis*, is not usually met with in this form, and is in any case a character of specific rather than generic significance.

Because of the limited knowledge of Silurian Rhynchonellids, it is difficult to give an adequate diagnosis of *Rhynchotreta*, especially as in Britain and Scandinavia only one species has so far been definitely recognized as referable to this genus, so that there is little evidence as to the constancy or variation of any given characters.

The writer would attribute most importance to such characters as the dentition, and to the assemblage of structures at the posterior region of the dorsal valve. The position of the crura, crural bases, hinge-plate, and rostral cavity reflect to some degree the arrangement of the musculature, and afford perhaps the best general guide to the muscular system in view of the indistinctness of the muscle impressions that almost invariably prevails. The following generic diagnosis is thus proposed, which it is thought will include, too, the other American species referred to this genus.

Diagnosis.

Small, subtriangular, strongly plicate Rhynchonellids, with a median sinus in the ventral valve and corresponding fold on the dorsal. Ventral umbo high, pedicle foramen apical or subapical; delthyrium closed by deltidial plates, which are united in close suture along the median line. A specialized dentition; in the ventral valve, strong dental plates supporting stout teeth, which articulate with sockets in the dorsal valve on either side of the hinge-plate. In the dorsal valve a small, almost sessile hinge-plate, bearing on the upper surface the crural bases, which define a rostral cavity. Crura short, simple.

Range.

(As at present known.) The Silurian of Europe and North America.

Types.

Genotype, *Terebratula cuneata* Dalman, 1828 *K. svenska Vet. Akad. Handl.* (for 1827), 141, Tab. vi, figs. 3*a*–*c* (if still existent).

Genoneotypes, *Rhynchotreta cuneata* (Dalman), Sedgwick Museum A 8778–8781 from Klinte, Gotland [Lindström Collection].

Acknowledgments.

The writer wishes to express his thanks to Dr. Hägg for permission to examine material in the Naturhistoriska Riksmuseum, Stockholm, and to Dr. Warburg for access to specimens at the Palaeontological

Institute, Uppsala. This paper has been written during the tenure of a grant from the Department of Scientific and Industrial Research and of a Goldsmiths' Company Senior Studentship, and the writer wishes to acknowledge his indebtedness to the authorities concerned in these awards.

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Intrusion of Cone-Sheets

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(PLATES VIII AND IX.)

THE visitor to Mull and Ardnamurchan finds himself face to face with a host of fascinating volcanological problems, that were brought to light by the unsurpassed accuracy of the field-work and its imaginative presentation by the officers of the Geological Survey. From a mechanical point of view the cone-sheets are perhaps the most startling of all, for they do not appear to fit in with the facts that have so far been ascertained from the study of active volcanoes. The ring-dykes are no less interesting, but their existence is not so puzzling. In fact, they appear to stand in direct relation to the mechanism that is responsible for the formation of many, if not most, calderas of recent volcanoes.

In the Mull memoir Anderson showed that the formation of cone-sheets may be explained by an excess of magmatic pressure acting vertically upwards, that would cause a series of fractures to develop, along which the magma intruded. No field evidence is presented, however, to show that there was any central uplift attendant on the intrusion.

In the Ardnamurchan memoir Richey adopted the above theory, adding confirmatory evidence in the section, fig. 24, p. 175. Here the Trias in the upper wall of a multiple cone-sheet is represented as having been lifted by a movement *at right angles* to the plane of the sheets (= a in Text-fig. 1, D; b is the resultant uplift). But in calculating the total amount of uplift caused by all the cone-sheets of centre 2, Richey assumes the movement to have been *vertical* (= c in Text-fig. 1, D). Certainty as to the exact sense of the displacement caused by cone-sheet injection is therefore not yet available.

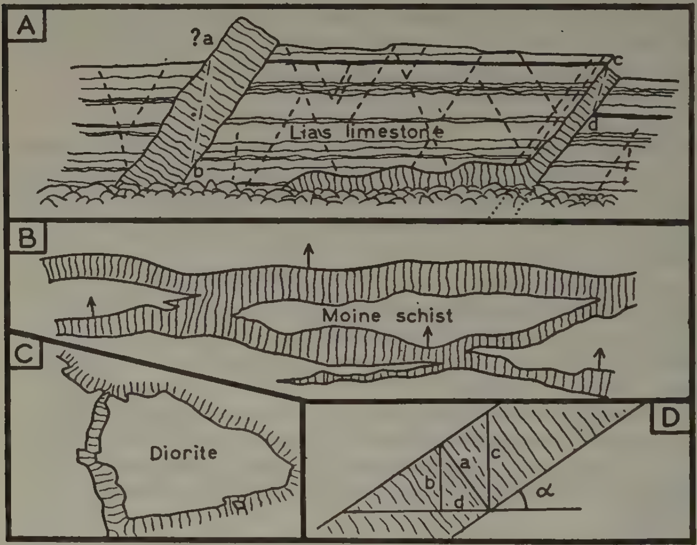
The problem is of sufficient importance to warrant further study. During a short stay at Kilchoan in Ardnamurchan, and in Mull, the writer attempted to assemble further evidence in regard to these matters. The following data appear to bear upon our problem.

In the first place it should be noted that there is no dragging, crushing, or slickensiding of the cone-sheet walls, so that there was no slipping along pre-existing faults or fractures marking the plane of injection (Plates VIII and IX). This is borne out by the minor details of the walls (Text-fig. 3, A).

In the excellently exposed stream section of the late basic cone-sheets in Glen Clachaig in Mull, and at various points along the south coast of Ardnamurchan, one frequently meets with examples where the two sides of a cone-sheet can be fitted accurately together. Especially the larger irregularities of the opposite sides match in a satisfactory manner. This, together with the almost complete absence of inclusions, the surprisingly uniform composition of the intruding rock and the chilled edges, proves beyond doubt that the cavity occupied by the cone-sheet was opened neither by stoping nor by assimilation, but solely by the dragging apart of the walls.

The fitting of the two walls, especially in sheets following a zig-zag course (Text-fig. 3, D), further proves that no great horizontal or vertical displacement accompanied the injection.

Closer examination of these walls shows, however, that where these are rather irregular the smaller details of the shape are seldom found to correspond at both sides. (See Text-fig. 1, B and C.) From this it can be deduced that the widening during the injection was not in the horizontal direction, but was slightly up or down.

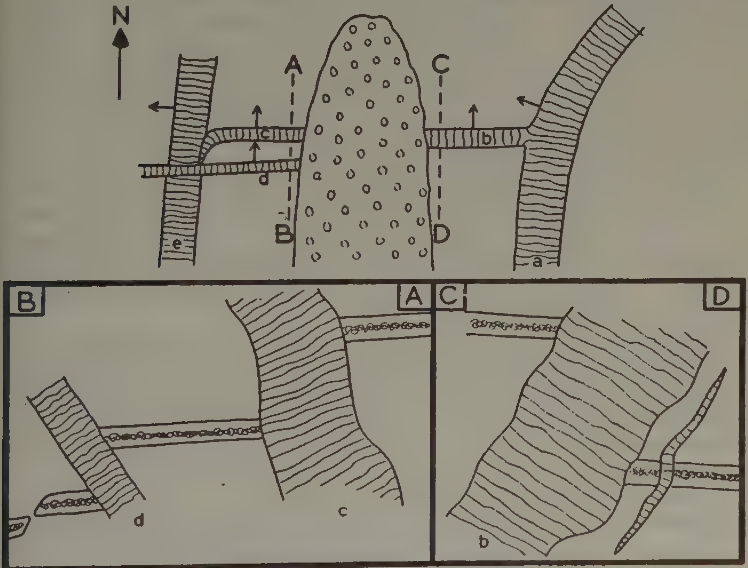


TEXT-FIG. 1.—A, Cone-sheets and joints in Lower Lias limestone south-west of Mingary Pier. B, Splitting cone-sheet in Moine schist, south of Kilchoan. C, Walls of cone-sheet, ill-fitting as to minor details, Clachaig Valley. D, Measurements of a cone-sheet.

Sill off-shoots are found both in the upper and lower walls of cone-sheets. Dyke offshoots with échelon-structure are also met with (Text-fig. 3, C).

Besides these more general aspects there is the evidence mentioned above of elevation of the central (=upper) wall of a multiple cone-sheet at Mingary Pier.

A few yards to the west further information is obtained. A small recess floored by beach-gravels runs into a cliff formed of Liassic limestone cut by cone-sheets. (Text-fig. 2.) A thin sill with a spheroidal centre, being earlier, furnishes an excellent means of measuring the vertical component of the movements accompanying the cone-sheet injection. The normal cone-sheet a, sends off a branch b, that splits into c and d, dipping north. This furnishes us with four cases, all of which show the upper wall to have been lifted by the emplacement of the corresponding sheet (Plate VIII, Fig. 1). In all cases the amount is more than corresponds to a movement at right angles to the walls, but less than the vertical distance from a point of the upper wall to the lower (therefore between a and c, Text-fig. 1, D).



Text-fig. 2.—Map and two sections of cone-sheets south of Mingary Pier.

The hard shale bands in the Liassic limestones around the cone-sheet, figured by Richey (1933, pl. i, B), can also be used as datum levels (Text-fig. 1, A). At the two sides of this particular sheet the vertical displacement is more than the exposed thickness of the strata (from b to a at least). This is more than the thickness of the sheet measured vertically. From analogy with the other cases we may suppose the upper wall to have been lifted.

A few yards to the right a small cone-sheet is exposed with a sill offshoot, and here the upper wall has been lifted more than the vertical thickness. The partings of shale in the upper wall are seen to overlap the corresponding ones of the lower wall (Fig. 1, A and Pl. VIII, Fig. 2).

We are thus able to show that in all the six cases in which the sense of the movement is ascertainable, the upper wall has been lifted. From the seven cases giving an indication of the amount, the average corresponds roughly to the thickness of the sheet in question, measured vertically (= c in Text-fig. 1, D).

It is to be hoped that future visitors will check and amplify the evidence here presented. The chief difficulty in determining the movements is due to the scarcity of suitable datum levels for measurements. However, the data already available seem conclusive as to the general sense of the displacement. The amount is still open to doubt and may possibly vary from case to case.

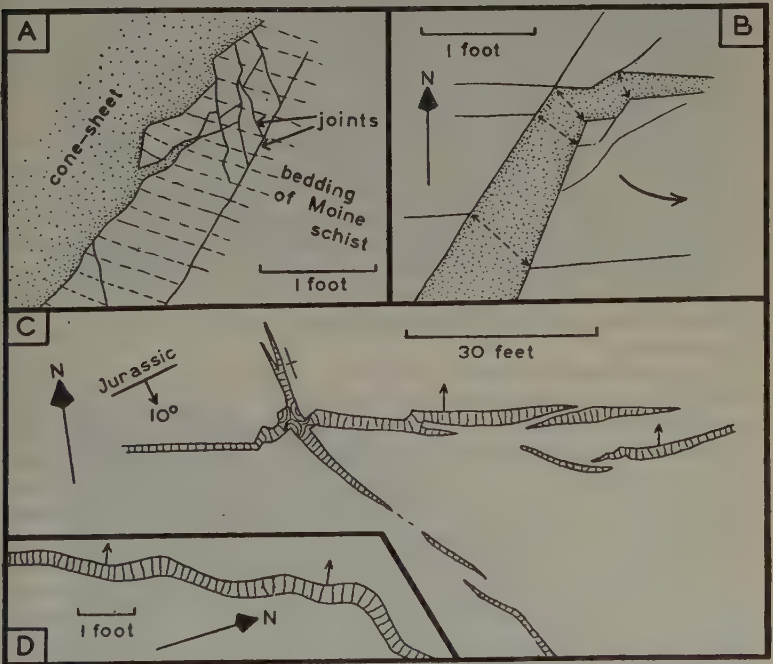
Richey found fracture-planes unfilled by magma in the limestone parallel to the cone-sheet on the left of our Text-fig. 1, A. As, however, there are also numerous similar cracks dipping in the opposite sense or cutting across the trend of the sheets, the writer is inclined to consider them all as normal joints. The intruding cone-sheets made use of the joints that happened to coincide with their direction, in the same manner as offshoots followed the fissility provided by the bedding planes to form small sills.

Other instances in which the cone-sheets have made use of pre-existing joints are represented in Text-fig. 3, A and B. Such cases are, however, exceptional. The exposure of Text-fig. 1, A, does *not* appear to demonstrate conclusively that *new* cracks were made parallel to the cone-sheets and by the same mechanism, *without their having been filled by magma.*

Turning to the more theoretical aspects of the problem our observations appear to confirm Anderson's theory that cone-sheets are injected under the influence of increased pressure in the magma reservoir. As no individual cone-sheet runs for more than a few degrees round the circumference of the circle followed by its group, it is not impossible from a stereometric point of view, that the upper wall moved horizontally towards the centre or even down. If the cracks were formed by some kind of central sagging this effect would be expected. But the observed lifting of the upper wall is definitely opposed to this possibility. With the supposition of movement at right angles to the dip of the cone-sheet, there would also result a horizontal movement towards the centre (d, Text-fig. 1, D). The writer's deduction of a purely vertical movement (as average) is not only the simplest stereometrically, but it is also exactly what would be expected on Anderson's theory. There is no element in his theory to provide for anything but a purely vertical, or even slightly over-thrusting movement.

Various properties of cone-sheets appear to indicate that the formation of the fracture and the consequent injection happened suddenly. Cone-sheets cut through the country rock with like regularity as to shape and position, whether the intruded rock is formed of massive ring-dykes, friable sediments, loosely compacted agglomerates or older cone-sheets. Pre-existing joints and other lines of weakness that do not happen to lie parallel to the plane of injection of the group (and the line of injection of earlier cone-sheets) are only made use of by way of exception. These points suggest that the fracture was caused by a very short and sharp " blow " delivered from below, precluding search for the line of least resistance by the crack. One might compare the process to the punching of a conical hole in glass by a bullet as contrasted to the shattering by a thrown stone.

The magma must have followed up immediately as it fills the fracture almost without making use of other earlier lines of weakness. This, together with the absence of enclosures rent from the walls and the undisturbed condition of the country rock, implies a very mobile magma of high temperature, that reached its destination before cooling caused increase of viscosity.



Text-fig. 3.—a and b. Lower wall of—and offshoot from—cone-sheets south of Kilchoan, making use of pre-existing joints in Moine schist. c, Cone-sheet with dyke-offshoot, both with échelon structure in Jurassic strata east of Srōn Bheag, d, Zig-zagged cone-sheet south of Kilchoan.

By the swift injection the heat was, as it were, directly spread out over the whole surface of the sheet. This prevented assimilation, the absence of which was noted above.

An abrupt character of the individual injection is also in accordance with the intermittent nature of the whole injection process. The magma forming a set of cone-sheets was emplaced by a number of separate acts of intrusion which yielded each only a fraction of a per cent of the total amount. When the increase of pressure is imagined to be of an explosive, momentary character, only a small injection of magma need result, but with a slow and gradual exertion on the part of the magma one would expect a large proportion to be intruded during a slow influx before a balanced condition was again obtained.

In what manner the sudden rise of magmatic pressure is brought about remains an open question, as also the reason why the magma remained for long-continued periods almost unaltered in composition by either differentiation or assimilation.

In conclusion, the question should be considered why the central lifting of thousands of feet during the injection of a set of cone-sheets has not yet been observed in recent volcanoes.

It appears most unlikely that cone-sheets, although undoubtedly a rare phenomenon, should be a quite exceptional feature confined to half a dozen ancient Scottish Tertiary volcanoes, and entirely absent from Quaternary and recent volcanism. The fact that they have never been found at or near the surface of an undenuded volcano does not imply their total absence, for it can be explained equally well by inability of cone-sheets to cut up far into the body of the volcano, perhaps by their continuing into sills as they approach the surface.

Even deep-seated injection might be questioned on the grounds that the bodily elevation of practically the whole cone should still be apparent. This, however, would necessitate an accuracy of topographic measurement as yet unattained. The period occupied by the emplacement of a whole set of cone-sheets is very long. Not only was there time between the injection of two successive sheets for the first to have consolidated, but in the Mull memoir it is proved that the period for a whole set occupies a considerable portion of the whole volcanic history of the region. We may take this portion as being of the order of 100,000 years at the very least. The central elevation is thus found to average less than one inch per year, or *one cone-sheet every few hundred years.* Accurate and constantly repeated levelling of several points on a number of active volcanoes, especially after severe earthquakes, may some day reveal a sudden uplift of a few feet. This would enable us to conclude that cone-sheet injection is active also in recent times, although nothing is directly seen at the surface.

SUMMARY.

Evidence from Mull and Ardnamurchan is brought forward to show that the injection of cone-sheets is accompanied by a vertical lifting of the upper wall. This confirms Anderson's explanation. It is argued that the fracturing and injection are of a quite sudden character and that it is in the nature of the process that no evidence from recent volcanoes has yet been obtained of contemporary cone-sheet injection.

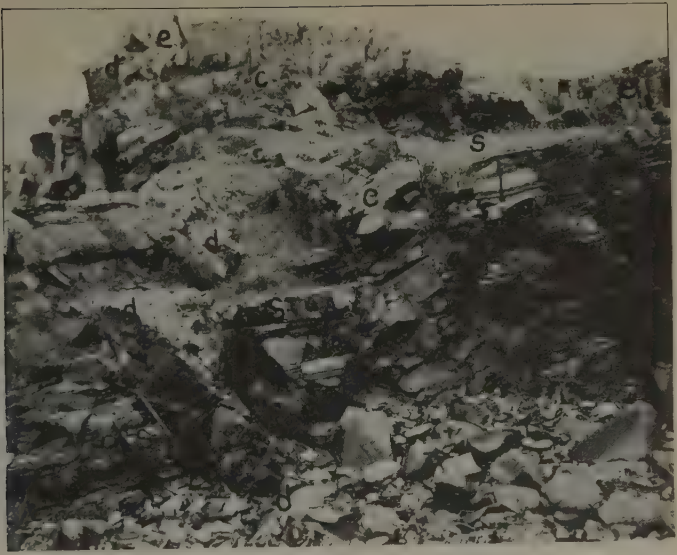


FIG. 1.

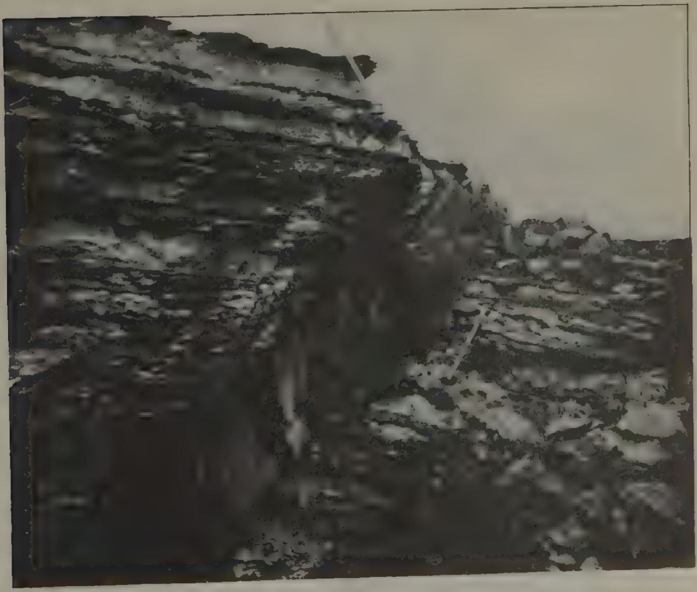


FIG. 2.

CONE-SHEETS NEAR MINGARY PIER.

[*To face p.* 182.

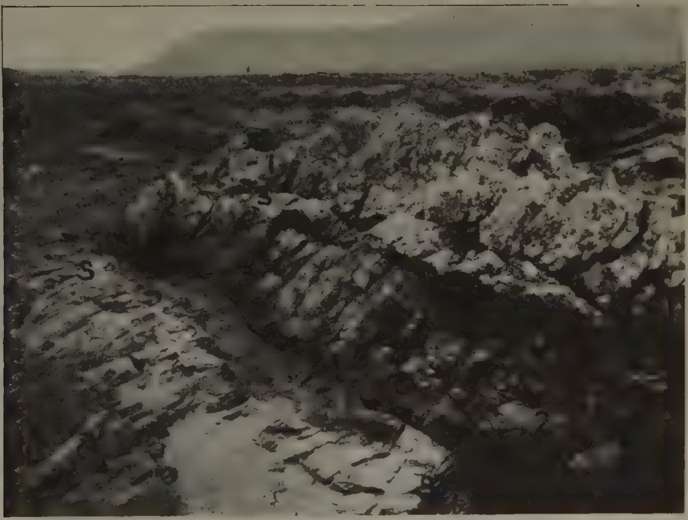


FIG. 1.

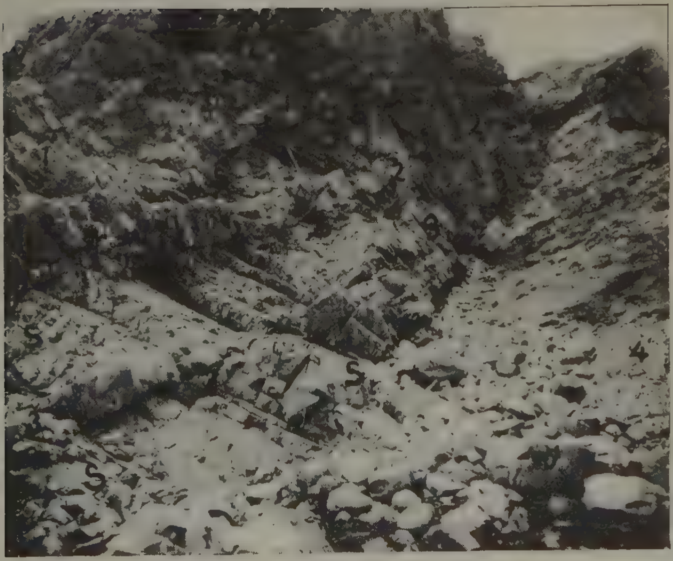


FIG. 2.

CONE-SHEETS SOUTH OF KILCHOAN.

REFERENCES.

HARKER, A. "The Tertiary Igneous Rocks of Skye," *Mem. Geol. Surv., Scotland*, 1904.
BAILEY, E. B., etc. "Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban," *Mem. Geol. Surv., Scotland*, 1924.
RICHEY, J. E. "The Geology of Ardnamurchan, North-West Mull and Coll," *Mem. Geol. Surv., Scotland*, 1930.
—— "Summary of the Geology of Ardnamurchan," *Proc. Geol. Ass.*, xliv, 1–56, 1933.
—— "Guide to the Geological Model of Ardnamurchan," *Mem. Geol. Surv., Scotland*, 1934.

EXPLANATION OF PLATES VIII AND IX.

PLATE VIII.

FIG. 1.—Two cone-sheets cutting sill in Liassic limestone. Corresponding to section A–B, fig. 2, for lettering see map.
FIG. 2.—Cone-sheet on the right of fig. 1, A. The hammer-heads rest on corresponding parts of shale bed.

PLATE IX.

Cone-sheets south of Kilchoan 1–1, 2–2, etc. Screens of undisturbed country rock, consisting of Moine Schists s–s.

The author is willing to supply stereoscopic prints of the photographs on request.

On the Carboniferous Fish *Eucenturus paradoxus*, Traquair.

By J. A. MOY-THOMAS, Dept. of Zoology and Comparative Anatomy, Oxford.

A REMARKABLE little fossil fish, *Eucenturus paradoxus*, was described by Traquair (1905) from a single specimen from the Calciferous Sandstone Series of Ardross, Fifeshire. Traquair's description is as follows: "This extraordinary little organism measures 2⅜ inches in length, of which ½ inch may be allotted to the head, and ¾ inch to the body, and 1⅛ inch to the tail. The head is a mass of calcareous matter, in which something suggestive of a broad curved mandible can be seen, but admits of no further description. The body, ⅜ inch broad in front, is composed of a greyish film, which, when examined by a strong lens, is seen to consist entirely of minute, slender, slightly-curved and sharp-pointed spinelets. The tail is tapering in form, consisting of amorphous-looking calcareous matter, but on each side (assuming that the creature is crushed vertically) is a conspicuous row of double spinelets arranged exactly opposite each other. From a common base arise two spinelets, which are placed close together, and nearly parallel to each other; one of them, the anterior, being only half the length of the posterior one, which just behind the body may attain a length of $\frac{1}{16}$ inch, though towards the end of the tail they become smaller;

both spinelets are slender, slightly curved, round in transverse section, smooth externally, sharply pointed, and traversed internally by a central tubular pulp cavity. No trace either of internal skeleton, or of limbs, or of fins of any sort can be seen."

Unfortunately no further material of this fish has been collected since Traquair's description, but a re-examination of the type specimen under xylol and other liquids has revealed several new points in its anatomy, which seem to throw some further light on its affinities.

Perhaps the most interesting new addition to our knowledge is that the structure described by Traquair as " something suggestive of a broad curved mandible " is a tooth-plate similar to those of Bradyodont fishes. This is made clear by the parallel vertical tubules of dentine which can be seen along one broken edge, without making a section, under the high power of the binocular microscope.

There are distinct remains of limb girdles, certainly the pectoral and also probably the pelvic. The whole tail can be seen to have calcified centra in the vertebral column. These would presumably be normally continued back to the skull, but a considerable portion of the body is missing in this region, and only a relatively very small part of the head is still preserved.

Discussing the affinities of *Eucenturus* Traquair remarks that the nature of the dermal armature would suggest a selachian " although all other evidence to that effect is wanting ". In addition to these denticles the limb girdles and tooth-plates leave little doubt that it is an Elasmobranch. The possession of Bradyodont tooth-plates and calcified vertebral centra at once suggests affinity with the Lower Carboniferous Elasmobranch *Chondrenchelys problematica* (Moy-Thomas, 1935 and 1936). *Eucenturus* differs most obviously from *Chondrenchelys* in having relatively large spinelets on its body, these, however, are by no means uncommon among the Bradyodonts. It may therefore be concluded that *Eucenturus* is a Bradyodont, but a member of a hitherto undescribed family of this group.

The type and only specimen of *Eucenturus* is in the Royal Scottish Museum, Edinburgh, and I would like to express my thanks to Dr. A. C. Stephen for allowing me to examine this specimen.

MOY-THOMAS, J. A. 1935. " On the Structure and Affinities of *Chondrenchelys problematica*, Tr.," *Proc. Zool. Soc. London*, 391–403.

—— 1936. " On the Structure and Affinities of the Fossil Elasmobranch Fishes from . . . Glencartholm, Eskdale," *Proc. Zool. Soc. London*, 761–788.

TRAQUAIR, R. H. 1905. " Notes on the Lower Carboniferous Fishes of Eastern Fifeshire," *Proc. Roy. Phys. Soc. Edinburgh*, vol. 16, 80–86.

REVIEW.

AN ATTEMPT AT THE CORRELATION OF THE ANCIENT SCHISTOSE FORMATIONS OF PENINSULAR INDIA. By SIR LEWIS FERMOR. *Memoirs of the Geological Survey of India*, vol. 70, part i, pp. 51. 1936. With one map.

THE memoir, Part I of which is the subject of this review, is a comprehensive discussion on the Archaean rocks of India from the pen of Sir Lewis Fermor; the remaining parts are to appear from time to time during, it is hoped, the next few years.

The most recent geological map of India appeared in 1931. No description of the geology of the country was published with the map; Sir Edwin Pascoe is now engaged in compiling such a description, and this will appear at an early date as a Manual of the Geology of India. Some 60 per cent. of the area of the Peninsula is occupied by crystalline rocks and it is to be expected, perhaps, that these should receive a more detailed treatment that can be incorporated in a manual. It is such a treatment that Sir Lewis now contemplates.

Those of us who have worked on metamorphic rocks and have also visited areas of metamorphic rocks in other countries will appreciate something of the task which Sir Lewis has set himself for India. In this country we have had detailed mapping in widely separated areas, and attempts at correlation may be compared, perhaps, to attempts at correlating the rocks of the Lake Superior region with metamorphic rocks in the Alleghanies, the Black Hills, and in the Rockies, or between Scotland, Scandinavia, and Central Europe. Unfortunately we are too prone to think of the country as a geological entity, forgetting its vastness and the great distances separating the mapped areas. Except in a few isolated regions the geological map of India gives but a crude sketch of the Archaean rocks.

Detailed mapping on careful modern lines has been in progress for little more than twenty years; Sir Lewis makes the illuminating remark that "Most of our memoirs on the geology of Southern India were written before the introduction of the microscopic study of rocks into India". However, in Rajputana Dr. Heron's record of nearly 30 years of continuous mapping has resulted in the only satisfactorily completed areal unit in India. In other parts of India most of the work has been in progress continuously since the War. In the Central Provinces Sir Lewis Fermor's party has done some fine detailed mapping over a comparatively small area. In Bihar and the adjacent Eastern States Agency, a party, centred around Singhbhum, has covered a rather larger area in detail. Recently a survey party commenced work in Bastar State, which should clear up some of the problems of the Charnockites and related rocks. Geological surveys in South India have gone on continuously, but no connected account has appeared in recent years. These facts will indicate the real paucity of connection between these isolated areas.

Part I is introductory in nature, its principal object being to discuss the several factors which may be concerned in correlation and to divide the country into provinces of a size suitable for description. One may note, at the commencement, that the memoir's title is not perhaps correct seeing that the author intends to describe rocks beyond the Peninsula—in Ceylon, Burma, and the Himalayas.

On page 5 Sir Lewis re-quotes his definition of the term Archaean made in 1909; the arguments surrounding the use of the term *eparchaean unconformity* form nothing more nor less than a vicious circle. Cut down to the root of the matter the true definition is found on page 14: "I have taken the presence of either granitic or pegmatitic intrusives as sufficient reason for referring the rocks into which they are intruded to the Archaean rather than the Puranas."

In the excellent discussion of the well-known factors involved in correlation Sir Lewis brings up again the question of crush-conglomerates. I think, from their recent work, several Mysore geologists will demur at the statement: "In the Dharwar series of Mysore there are many conglomerates, but these are all regarded by the Mysore geologists as probably due to crush." Except in Sir Lewis's own area, Central Provinces, this mode of origin for sheared conglomerates seems to have died, leaving no regrets.

Apparently the author intends to make some use of the manganese occurrences in correlation. This is dangerous ground of which, no doubt, he is well aware. In the Iron-ore series there is a manganiferous shale horizon near the base and another near the top. Similarly in the use of the iron-ores for the same purpose, although the Iron-ore series is the main source of iron-ores, the pebbles in the basal conglomerate indicate that iron-ores occurred in an older series.

There are several minor points with which some petrologists will not agree, such as metasomatism as an occasional factor in metamorphism, and the solvent action of water in metamorphism, but until we come to the discussion on charnockites there is nothing to cause serious disagreement from the point of view of the purpose of this memoir. Sir Lewis appears to have accepted Stillwell's view that the charnockites are metamorphic rocks of the hypo-zone. Many of us were of this view until recently, but some of us would now revert, in part, to Holland's original description of them as normal igneous rocks. May they not be rocks formed by the crystallization of a dry magma at great depth? In discussing, on page 50, why the Cuddapahs never come in contact with the charnockites, Sir Lewis gives two reasons. I suggest to him a third: the charnockites were intruded at such great depths that they were nowhere exposed at the surface up to the time of deposition of the Cuddapahs.

For the infra-plutonic zone the author has made a good case, and many of us will agree to the probability of his eclogite shell. Its suggested influence in the causation of earthquakes is unconvincing.

Finally, Sir Lewis explains the manner in which he has divided India (unfortunately he heads his table "Peninsular India") into regions and provinces for purposes of description. The three regions: Non-charnockite, Charnockitic, and "extra-Peninsular provinces" give an unbalanced division so far as area is concerned, and especially so when we note that probably 95 per cent of the work to date has been done in the non-charnockite region. From the metamorphic point of view it is not a petrological division and gives neither a picture of facies nor of grade. It is simply a convenient description of areas, the charnockitic region covering merely the southernmost tip of the Peninsula and the east coast, the non-charnockitic being the rest of the Peninsula.

The eighteen subdivisions, or provinces, are on an areal basis, but they are grouped into types, some of which are, at least in name, lithological: in the non-charnockitic region there are the iron-ore provinces, the (manganese-ore)-marble provinces and the igneous provinces; in the charnockitic region there are the iron-ore provinces, (manganese-ore)-marble provinces and the garnetiferous provinces; the extra-Peninsular provinces are grouped (naturally) into the Himalayan and Burma occurrences. The grouping contains elements of lithological types, elements of facies and elements of areal distribution—a real hotch-potch! Several of the groups contain common characteristics. It might just as well have been left entirely areal. However, classifications of this nature are entirely for clarity in description, and I would not advise the reader to give to it, at this stage, any other significance.

J. A. Dunn.

REPORTS AND PROCEEDINGS.

Mineralogical Society.

11th March, 1937.

(1) A universal ore-polishing machine. By Dr. F. Coles Phillips.

A short account of the construction and use of a two-lap polishing machine available both for the usual methods of polishing by hand and for the automatic method developed at Harvard University. A description is given of the method of mounting specimens in synthetic material.

(2) On the occurrence of turquoise in Cornwall. By Mr. Arthur Russell.

(3) The deuteric mineral sequence in the Enoggera granite, Queensland. By Miss MARJORIE J. WHITEHOUSE. (Communicated by the President.)

The minerals found in veins and vughs in this granite near Brisbane are described. The period of main magmatic consolidation was followed by pegmatite formation and the initiation of cavities in the rock. While the rock was still hot the deuteric period occurred beginning with the kaolinization of the felspars and the chloritization of the ferromagnesian minerals. Then followed the deposition of chlorite and epidote, the pneumatolytic minerals, some calcite, the zeolites, and, finally, many vughs were completely filled with calcite.

(4) X-Ray data on rhodonite, pyroxmangite, and iron-rhodonite. By Mr. M. PERUTZ. (Communicated by Prof. C. E. TILLEY.)

CORRESPONDENCE.

THE GIRVAN-BALLANTRAE SERPENTINE.

SIR,—In the January issue of the GEOLOGICAL MAGAZINE, Mr. Balsillie restates with additional detail his hypothesis that the serpentine of the Girvan-Ballantrae district forms part of an ancient, probably pre-Cambrian, basement unconformably overlain by Arenig volcanics and subordinate sediments. I have already taken account of several points raised by Mr. Balsillie in a note (GEOLOGICAL MAGAZINE, December, 1936), furnishing unequivocal evidence in support of Peach and Horne's conclusion that the serpentine is intrusive into Arenig lava and forms, in fact, one of the plutonic members of the Arenig igneous suite. Mr. Balsillie, however, in an addendum to his paper, asks me to explain the high grade of metamorphism and the north-west foliation found in the serpentine and absent from adjacent Arenig lavas. I am entirely unconvinced that any part of the serpentine itself can be described as consisting of highly metamorphosed rocks, although these are admittedly found as associates. In particular hornblende and epidote schists marginal to the northern belt of serpentine have been considered in my December paper (pp. 539–542), and their significance as regards the question at issue between Mr. Balsillie and myself pointed out. As regards the north-west foliation, I have not been able on search to verify its existence. In this case I think Mr. Balsillie is attaching undue importance to something that must be rather difficult to observe. Furthermore, it may be mentioned that localization of dynamic structures in the serpentine is not in itself particularly strong evidence of age-relationship, if one bears in mind the much more resistant nature of the spilite as compared with the altered ultra-basic rock.

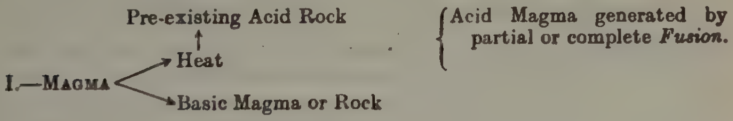
J. G. C. ANDERSON.

UNIVERSITY OF GLASGOW.
28th January, 1937.

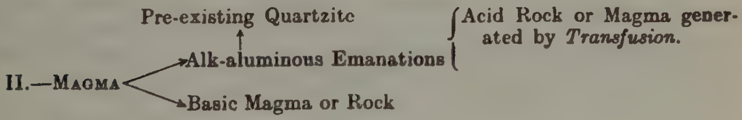
THE IDEA OF CONTRASTED DIFFERENTIATION.

SIR,—The *Reply* by Dr. Nockolds (3) to my paper (2) shows that confusion still remains on the essential point at issue—the validity of his idea of contrasted differentiation. The attempt to weaken the force of my adverse criticism avoids the issue and does not carry us any further. Nockolds originally wrote (1, p. 34): " There is clear evidence that differentiation in intercrustal magma basins yields two contrasted magma types, acid and basic." Having no knowledge of this " clear evidence ", I asked what it was (2, p. 235), but none is given in the *Reply*. The observed association of contrasted magma-types is knowledge we share ; it is no more evidence of contrasted differentiation than the observed association of toys and stockings on Christmas morning is evidence of the reality of Santa Claus.

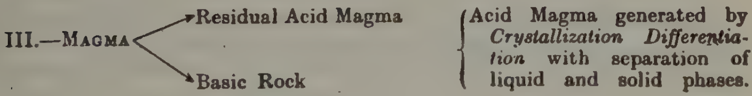
Nockolds writes (3, p. 530): " If, therefore, the acid and basic portions in, say, a composite minor intrusion come from a common source, I see nothing wrong in saying that they have differentiated from that source." Granting the *if*, there is, of course, nothing wrong. But that all important *if* cannot be granted until there is positive evidence that the acid and basic portions did come from a common source. Theoretically, it is just as possible that they did not come from a common source, or that they did so only in part. Of the very large number of theoretical possibilities which can be imagined, the three schematically outlined below are sufficiently representative for the present discussion. Not merely one, but all of these must be tested by the evidence available.



Acid Magma generated by partial or complete *Fusion.*



Acid Rock or Magma generated by *Transfusion.*



Acid Magma generated by *Crystallization Differentiation* with separation of liquid and solid phases.

I.—A process which is difficult to distinguish from II, of which it is a limiting case. See C. Sorochinsky (4).

II.—A particular instance of a kind of syntexis in which the amount of energy and the compositions of both the emanations and the pre-existing rocks affected by them may vary widely. For examples of evidence see Doris L. Reynolds (5) and A. Holmes (6) and the papers referred to therein. The position is far from being as hopeless as Nockolds makes out, when he writes (3, p. 535) of " a process of gaseous distillation in which rocks are acted upon by unspecified emanations (in an unspecified manner) coming from an unknown source at unknown depths ". When manifest effects cannot be explained by prevailing conceptions, what can be more scientific than to attempt to discover the unrecognized factors ? Many of us are engaged in research directed to this end ; we seek to determine the nature of the emanations responsible for observed effects in particular cases. To trace their immediate source is not usually difficult, but it would be an unwarranted assumption to pretend that the immediate source is the ultimate source. To the physicist, cosmic rays present a similar incentive to research : these rays, which are perplexing realities, derive their energy from some unknown ultimate source in the depths of space. Emanations, equally real, derive their energy from some unknown ultimate source in the depths of the earth.

III.—A process of crystallization differentiation followed by separation, which is advocated by Nockolds to account for the association of acid and basic rocks. I do not deny that there is a contrast in composition between the acid material in, say, a quartz-dolerite or tholeiite and the crystal-mesh through which it is distributed. What I pointed out was the mechanical impossibility of bringing about separation except by the application of powerful stress. I have no objection to the idea of contrasted crystallization differentiation where the rocks themselves afford evidence of the operation of stress. See N. L. Bowen and J. F. Schairer (7, p. 395). Nor do I object to the idea of contrasted differentiation where there is evidence of separation by some process of, or akin to, gaseous transfer—though, as indicated above, this is the basis of a different hypothesis. Whether the interstitial material is 5 per cent or 15 per cent makes no essential difference to the mechanical difficulties. It is easy to pour 15 per cent of water into sand, but it is impossible to get it out again except by evaporation or the application of stresses equivalent in their effects to those of dynamic metamorphism.

Nockolds writes (3, p. 533) : " If the final residuum of augite-andesites can ooze into vesicles when it only forms a very small proportion of the mass, there seems to be no reason why the acid residuum we are considering cannot also move quite readily." Again, the argument depends on the all important *if*. How can one know that the residuum oozed into " vesicles " ? Actually there are all gradations between xenoliths, transfused xenoliths, ocelli, and " vesicles " occupied by felsic material. See J. S. Flett (8) and R. Campbell, T. C. Day, and A. G. Stenhouse (9). What evidence there is points to dispersion *from* the felsic spots rather than to concentration *into* the felsic spots.

Nockolds' suggestion that my attitude is "strangely inconsistent" (3, p. 532), is a further symptom of the persistent confusion between evidence and interpretation. Any interpretation, hypothesis, idea, postulate, or supposition may, and should, be dismissed or modified when it is found to be at variance with evidence. Evidence of one kind, if it be genuine, cannot be at variance with evidence of another kind. Arising out of this point, I should like to say that I took conscious pains to write my paper (2) with particular care, having in mind that those who live in glass houses should not throw stones. I must therefore insist that statements which may be true of *crystallization differentiation* are not necessarily true of *differentiation*; that statements which may be true of *ultimate source* are not necessarily true of *immediate source*; and that statements which may be true of *interpretation* are not necessarily true of *evidence*.

The essential point of my paper was to demonstrate that the idea of contrasted crystallization differentiation, as hitherto developed, has not been shown to be valid. That idea, therefore, should not be used as if it were an established principle of petrology. Many petrological papers are marred by the failure to distinguish between interpretation and evidence, and if this discussion directs attention to the necessity of avoiding what has become a lamentably widespread departure from scientific method it should go far towards closing our ranks against future controversy.

ARTHUR HOLMES.

SCIENCE LABORATORIES,
SOUTH ROAD, DURHAM.
18*th December*, 1936.

1.—S. R. NOCKOLDS. "The Production of Normal Rock Types by Contamination and their Bearing on Petrogenesis," GEOL. MAG., LXXI, 1934, 31–9.
2.—A. HOLMES. "The Idea of Contrasted Differentiation," GEOL. MAG., LXXIII, 1936, 228–238.
3.—S. R. NOCKOLDS. "The Idea of Contrasted Differentiation: A Reply," GEOL. MAG., LXXIII, 1936, 529–535.
4.—C. SOROCHINSKY. "Étude pétrographique de l'édifice volcanique du Kahusi et du Biega (Kivu). (Mission géol. Com. Nat. de Kivu)," *Mém. Inst. géol. Univ. Louvain*, ix (vi), 1934, 98 pp.
5.—DORIS L. REYNOLDS. "Demonstrations in petrogenesis from Kiloran Bay, Colonsay. I: The transfusion of quartzite," *Min. Mag.*, xxiv, 1936, 367–407.
6.—A. HOLMES. "Transfusion of quartz xenoliths in alkali basic and ultrabasic lavas, South-West Uganda," *Min. Mag.*, xxiv, 1936, 408–421.
7.—N. L. BOWEN and J. F. SCHAIRER. "The Problem of the Intrusion of Dunite in the Light of the Olivine Diagram," *Rep. XVI Internat. Geol. Cong. Washington, 1933*, 1936, 391–396.
8.—J. S. FLETT *in* "The Geology of Caithness," *Mem. Geol. Surv. Scotland*, 1913, 113.
9.—R. CAMPBELL, T. C. DAY, and A. G. STENHOUSE. "The Braefoot Outer Sill, Fife. Part I: The Braefoot Promontory," *Trans. Edin. Geol. Soc.*, xii, 1931, 360.

RAISED BEACHES IN THE OUTER HEBRIDES.

SIR,—I have read with considerable interest the short section on Raised Beaches in the recently issued *British Regional Geology—Scotland, The Northern Highlands* (2) (pp. 95–6), and am surprised to note that " There are no raised beaches in the Outer Hebrides ".

On the remote island of North Rona, lying some 45 miles north-west of Cape Wrath and a like distance north-east of the Butt of Lewis, a deposit of fine-grained cemented material, enclosing fragments of both local and alien rocks, has been found some 30 feet above the present sea-level (4). Also on Roareim of the Flannan Islands, some 20 miles west of Gallan Head in Lewis, there is a similar deposit at a height of nearly 150 feet (5). Though small, both these deposits resemble the last remnants of raised beaches, which have suffered severely from subsequent (present-day) marine erosion, and have a similar appearance to the 30/50 ft. beach at Balnakiel, Durness, which has been described by D. M. Reid (3).

It also appears to have been overlooked that Professor Gregory has recorded a 10 ft. raised beach at Loch Maddy in North Uist (1).

In mentioning the Flannan Islands I should like to correct a clerical error that was missed in the proofs. On line 16 of page 115 and on line 6 of page 116 of the GEOLOGICAL MAGAZINE of 1933 " Eilean Ghobha " should read " Roareim ". This error was subsequently corrected in my book *Ronay* (6).

(1) GREGORY, J. W. "A Raised Beach on the Outer Hebrides," *First Report of the Commission on Pliocene and Pleistocene Terraces*, International Geographical Union, 1928, 119.

(2) PHEMISTER, J. *British Regional Geology—Scotland, The Northern Highlands*, Edinburgh, 1936, 95–6.

(3) REID, D. M. " On a Raised Beach on the North Coast of Scotland," GEOL. MAG., LXVI, 1929, 177–180.

(4) STEWART, MALCOLM. " Notes on the Geology of North Rona," GEOL. MAG., LXIX, 1932, 179–185.

(5) ——" Notes on the Geology of Sula Sgeir and the Flannan Islands," GEOL. MAG., LXX, 1933, 177–180.

(6) —— *Ronay; A Description of the Islands of North Rona and Sula Sgeir, etc., to which is appended a short account of the Seven Hunters, or Flannan Islands*, London, 1933.

MALCOLM STEWART.

HAWRIDGE COURT,
NR. CHESHAM, BUCKS.
29th December, 1936.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXIV.

No. V.—MAY, 1937.

ORIGINAL ARTICLES.

Note on *Anthraconauta calcifera* in the Upper Coal Measures of Denbighshire.

By Henry H. Simpson.

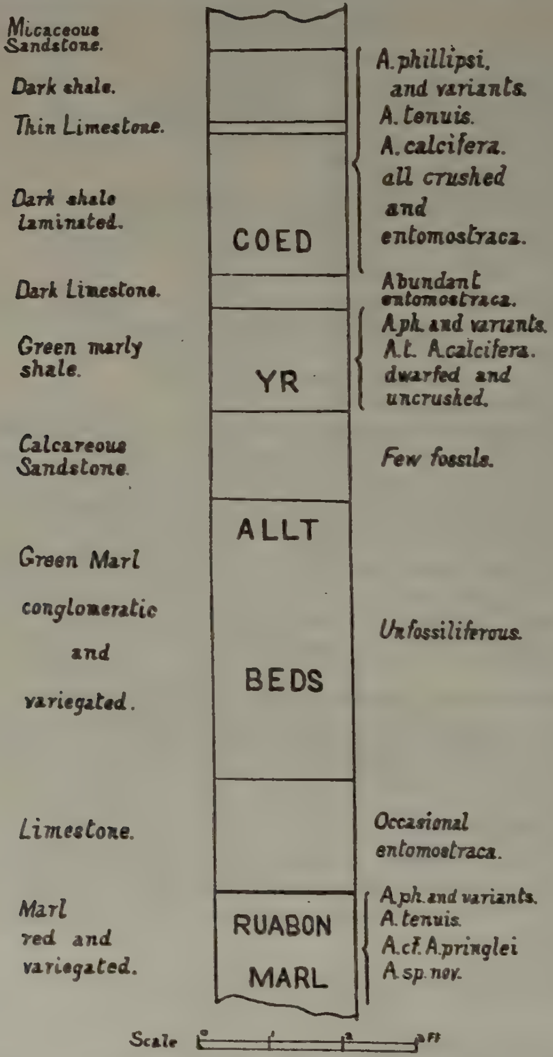
THE diminutive lamellibranch *Anthraconauta calcifera* (Hind) was described by Hind in 1899, and the specimens were from a limestone at the bottom of the Newcastle-under-Lyme Beds, the middle division of the Upper Coal Measures of North Staffordshire. Similar shells occur at the base of the Coed-yr-allt Beds, the middle division of the Upper Coal Measures of Denbighshire (Gibson, 1901) and further specimens have since been noted (Wedd, 1928). A critical study has recently been made of specimens of *A. calcifera* from the type locality in North Staffordshire (Dix and Trueman 1931).

An exposure at the junction of the Ruabon Marl and the overlying Coed-yr-allt Beds at Pont-y-cyffylogyn, near Ruabon, has recently been very carefully examined, and hundreds of shells collected, most of them in an excellent state of preservation in an uncrushed condition. The succession at this section is shown in Text-fig 1, and the following explanation is given in ascending order. The red marl where exposed is under water and in the meantime the collection of specimens from lower horizons is a matter of great difficulty. The approximate assemblage of lamellibranchs in the marl is as follows :—

A. phillipsi (Williamson)	approx. to type.	56	per cent.,	length up to	15 mm.
,, ,,	elongated.	14	,,	,, ,,	20 ,,
,, ,,	short.	14	,,	,, ,,	12 ,,
A. tenuis Davies & Trueman.		7	,,	,, ,,	15 ,,
Anthracomya cf. *A. pringlei* Dix & Trueman.		3	,,	,, ,,	12 ,,
Anthracomya, sp. nov. cf. *A. pulchra* Hind.		6	,,	,, ,,	10 ,,

The small shells below 5 mm. have not been included, as for the most part they are obviously immature, but none was seen which could be recognized as *A. calcifera* (Fig. 21, Plate XXV, Hind, 1904).

Above this the pale green conglomeratic marl is followed by a calcareous sandstone which gradually becomes a fine-grained, green,



TEXT-FIG. 1.—Vertical Section of the Ruabon Marl & Coed-yr-allt Beds at Pont-y-Cyffylogyn.

marly shale, with the first observed specimens of *A. calcifera* and only shells closely conforming in shape to Hind's type specimen are here determined as *A. calcifera*. The shells are dwarfed in this and the succeeding dark limestone, the largest specimen of any species measuring 8 mm. in length. The specimens above this point resume the normal size and appearance and run up to 20 mm. in length, but all are crushed and difficult to determine with any certainty.

The same beds outcrop in Pentre Issa Ravine, about half a mile to the south-west, where however the calcareous sandstone of Pont-y-cyffylogyn has become a flinty limestone and the marly shale above, instead of being green, is a light buff colour. This is the only visible difference between the shale at the two places, but the specimens are not dwarfed. *A. calcifera* occurs here in great numbers uncrushed and up to 13 mm. in length, together with *A. phillipsi* and *A. tenuis*. In the dark limestone with abundant entomostraca, higher up in the section at this locality, the shells are again dwarfed.

It has already been suggested (Dix and Trueman, 1931, p. 196) that *A. calcifera* is a dwarfed shell, and the above evidence confirms this, but in addition it suggests that *A. calcifera*, the type specimen of which only measures 5 mm., may attain a much greater size under favourable conditions.

I am indebted to Dr. W. B. Wright for the confirmation of the determinations.

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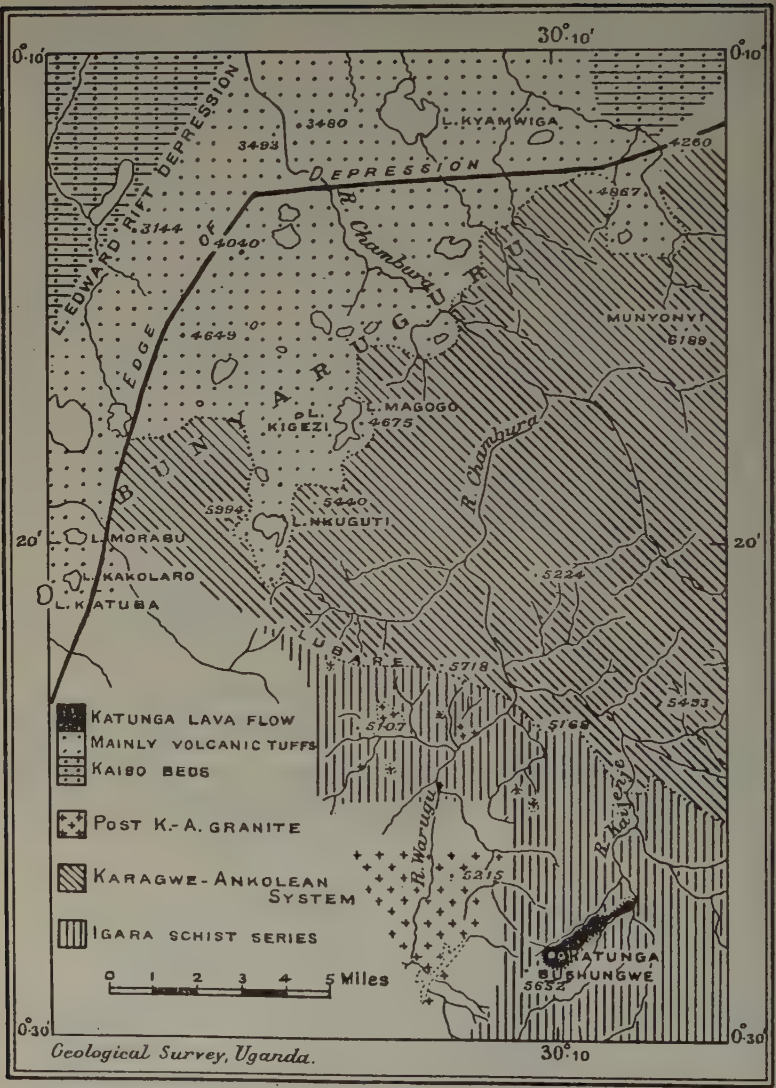
The Katunga Volcano, South-West Uganda.

By A. D. COMBE, Geological Survey of Uganda.

THE extinct volcano of Katunga (E. 30° 11′ 27″; S. 0° 28′ 17″ approx.) is in northern Igara which is part of western Ankole in south-west Uganda. The volcano is of special interest: (*a*) because of its isolation, the nearest neighbouring manifestation of volcanic activity being that in connection with the crater in which Lake Nkuguti lies, about 12½ miles to the N.N.W. in Bunyaruguru; and (*b*) because true lava-flows, the first to be discovered in the volcanic areas of north-west Ankole and Toro, composed of potash-rich olivine-melilitite (*katungite*), were extruded



Geological Sketch-map of part of North-west Ankole showing the Katunga Volcano and its Lava Flows.

from it. The volcano is an outlier of the southern edge of that part of the western volcanic field of Uganda lying in, and adjacent to, the portion of the western rift depression about the northern end of Lake Edward, the southern end of the Ruwenzori massif, and Lake George.

The following account is based on two brief examinations made in early March and mid-August of 1933. Previously no geological work had been done on the volcano or immediately adjacent to it and, apparently as a result of an oversight in draughtsmanship, the lake lying in the crater was not shown on the topographic map[1] of the area; and although it is well known to the local natives it had been visited by very few Europeans, and no information was available regarding its nature. A brief account of the Katunga volcano has already been published[2] and preliminary descriptions of different parts of the Bunyaruguru area have appeared.[3] Up to the year 1929 different parts of the western or Toro-Ankole volcanic area were examined by Wayland, Combe and Groves, and a detailed study of the petrology of many of the specimens collected has been made by Holmes with chemical analyses by Harwood.[4]

The volcano lies on the western side of Katunga hill and the highest point on the crater rim stands at about 5,600 feet above sea-level. It was built on a north-easterly trending spur of Bushungwe ridge (see south-east corner of adjoining map). The slopes of the volcano are steep and undissected and the highest parts of the crater rim are about 600 feet above the adjacent valley bottoms. The lower 200 feet or so is formed of rocks of the Igara Schist Series, on which the feature is built, and the slopes here are not so steep as higher up on the volcano itself, beyond the foot of which the toe of the spur projects in a north-easterly direction. The crater-lake, which is about 250 yards in diameter, is about 400 feet higher than the river beds on each side and it is without an outlet. The water is fresh and it was stated that there are no fish. The country surrounding the volcano is formed by rocks of the Igara Schist Series. It is hilly and much dissected and the ridges as a whole rise to numerous small, rounded, steep-sided hills. Bushungwe is a north-easterly trending ridge, several miles long, which rises at several points to over 5,650 feet above sea-level; it is the highest ridge in the Katunga area, as the adjacent ridge-tops are several hundred feet lower. The south-western side of the

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[1] Africa 1 : 250,000, Mbarara, $\frac{\text{South A—36}}{\text{A.}}$

[2] Combe, A. D., *Ann. Rept. for 1933, Geol. Surv. of Uganda*, 1934, paras. 305–311.

[3] Combe, A. D., *Ann. Rept. for 1929, Geol. Surv. of Uganda*, 1930, paras. 69–73; *Ann. Rept. for 1932*, 1933, paras. 157–160; and *Ann. Rept. for 1933*, 1934, paras. 312–325.

[4] Holmes, A., and Harwood, F. H., "Petrology of the Volcanic Fields East and South-East of Ruwenzori, Uganda," *Quart. Journ. Geol. Soc.*, lxxxviii, 1932, 370–442.

Buhwezhu mountain country, which is formed by shales, phyllites, and quartzites of the Karagwe–Ankolean, and is bounded by a steep escarpment-like ridge of quartzite, lies about 5 miles to the north of Katunga.[1] The eastern edge of the Lake Edward part of the western rift depression is about 14 miles to the west. A preliminary account of the surrounding country has already been published.[2]

The Igara Schist Series, which was formerly referred to as the "schists of unknown or doubtful age" is of pre-Karagwe–Ankolean age and it is made up of rocks displaying a high grade of metamorphism. They range from finely to coarsely foliated quartz-sericite, quartz-muscovite to quartz-muscovite-chlorite types, usually with plentiful black iron ore, and they appear to be metamorphosed sediments.[3] The schists are high-dipping and closely folded and they are invaded by biotite-granites. The general strike of the foliation is W.N.W.–E.S.E. and the dip is at high angles to the south-south-west.

The Katunga vent was drilled through the schists of the Igara Series. In places the latter form cliffs rising directly from the water and, as already stated, the spur on which the volcano is built consists of the same rocks, here containing numerous quartz veins and lenses. The crater rim and the outer slopes are almost entirely covered with elongated blocks and slabs of schist. Slabs on which have been carved the small cup-shaped hollows for playing the native game of *mweso* are numerous. A few bombs of lava were found and the only tuffs seen occur in occasional small exposures along the northern part of the crater rim.

A north-easterly running stream a little over 2 miles long, which is known as the Karuruma, rises immediately south of Katunga and to the west the Kyamahoro rises and also runs north-easterly, both streams flowing into the Kaijenje. The lavas from the volcano lie to the north-east in the strip of country between the two rivers; they were probably extruded from fissures, whence they passed down a valley sculptured in the schists, in most places filling the valley bottom. It is probable that the wide part was about the junction of two valleys with a low hump of schist between. There are two flows, which will be referred to in the following descriptions as the eastern and western, the upper parts of which are separated by the toe of the spur projecting to the north-east from the foot of the volcano; lower down, however, the flows lie side by side and form a continuous area of lava about 700 yards or so across.

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[1] Combe, A. D., *Ann. Rept. for 1932, Geol. Surv. of Uganda*, 1933, paras. 113, 114.

[2] Combe, A. D., *Ann. Rept. for 1933, Geol. Surv. of Uganda*, 1934, paras. 62–74.

[3] Combe, A. D., "The Geology of the Lubare Area, Western Ankole," *Bull. No. 3, Geol. Surv. of Uganda*, 1937.

The eastern flow issued from several points on the lower north-eastern slopes of the cone. Though lava apparently issued from several points, it is probable that there was one flow of much larger volume than the others. The flow is perhaps a little more than 1¼ miles long and it ranges from 50 to 400 yards wide, but where it begins it is from 10 to 15 yards across, increasing in width towards the foot of the mountain. The surface of the flow is moderately graded. The lava terminates at the Kaijenje river and there it is about 300 yards wide and from 10 to 20 feet thick, but for the last 200 yards the surface of the flow falls about 70 feet. There are no sections showing the thickness and internal structure of the flow, but in places there are exposures indicating at least 30 feet of lava. Adjacent to the toe of the spur on the north-east foot of the volcano the lava flowed round hummocks and over humps of schist and here it may be only a few feet thick.

The western flow was extruded on the northern slope of the volcano and passes down the mountain side to the bed of the Kyamahoro, a descent of about 300 feet. It begins as the point of a wedge and rapidly widens to as much as 50 yards across down to the bed of the river and then trends north-east. From the foot of the steep slopes the flow is nearly a mile long and it varies from 40 to as much as 400 yards wide. It is widest towards the end, where it passes round the extremity of the toe of schist and joins the eastern flow. The true thickness is not known but in places it appears to be about 20 feet.

Judging by the topography and the general characters of the lava area, it seems as if there was one large extrusion in each case and not a series of successive thin flows. The surface of the flows is generally even but there are occasional small piles of scoriaceous blocks. Ropy or pahoehoe forms do not occur, but sometimes along the edges of the flows the lava is blocky. Vesicular lava is not of frequent occurrence and is most commonly developed near the points of extrusion. The lava is nowhere dissected into land forms though there are some rounded boulders and a brown weathered crust is of frequent occurrence. Along the lower end of the lava area there is sufficient soil for the cultivation of food crops. As far as can be seen the flows are for the most part made up of solid rock with little ashy and scoriaceous material.

It is not clear which of the flows was the first to be extruded and it is probable that both were poured out together, or very nearly so. The age of the vulcanicity cannot be stated with precision, but it is, no doubt, contemporaneous with that in the main area of north-west Ankole in Bunyaruguru; that is, from late-Pleistocene to modern times. The little dissected condition of the volcano and the lava flows testifies to their modernity.

The lavas of Katunga vary from a stone colour through dun and blue-grey to nearly black. Most fresh surfaces display a greasy lustre, though some have a glassy or stony appearance. Crystals of yellow-green, light green, and very pale olivine, often of idiomorphic outline, and sometimes displaying definite crystal faces up to 2 and 3 millimetres long, and occasionally to as much as 12 millimetres, are plentiful. Microscope sections were examined by Simmons, who found the rocks to consist of olivine phenocrysts and melilite laths with perovskite crystals in a cloudy and mostly glassy groundmass strewn with small magnetite grains; he stated that they are olivine-melilite lavas of particular interest. A more detailed account, by Professor Arthur Holmes, appears in the paper that follows. The bombs are of lavas of the same general characters as those of the flows, and in some there are angular inclusions of Igara schist and vein-quartz.

The tuffs found on the crater rim are much weathered, but they are not calcareous. Individual layers are made up of lapilli of a generally even size together with angular fragments of mica-schist and vein quartz. The lapilli are of a dark grey lava with abundant yellow-green olivine. Well-shaped crystals of olivine as much as 3 millimetres long occur in the lapilli and also as separate individuals in the tuffs. So far as is known there are no limestones in the country adjacent to Katunga, the nearest exposure of limestone being the cliff on the eastern side of Lake Kigezi about 15 miles to the north-north-west.[1]

The Petrology of Katungite.

By Arthur Holmes, University of Durham.

(PLATE X.)

I. Petrography.
II. Chemical Composition.
III. Classification.
IV. Tuffs and Bombs.
V. Petrogenesis.
VI. Bibliography.

I. Petrography.

THE specimens representing the Katunga lavas are compact fine-grained porphyritic rocks of lustrous stone-grey to deep blue-grey colour, the phenocrysts being olivine (up to 3 mm. long) of various tints from nearly colourless to yellow-green, and melilite (up to 2 mm. square) in thin tabular, less conspicuous crystals which, megascopically, have a shining grey to black appearance. Some of the specimens from near the sources of the flows are internally altered and have become fawn or buff in colour, mottled by white zeolitic specks and reddish brown ferruginous pseudomorphs after olivine and melilite. Some weathered specimens have a brown ochreous crust, but within this the rock is normally fresh.

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[1] Combe, A. D., *Ann. Rept. for 1932, Geol. Surv. of Uganda*, 1933, paras. 157–160.

TABLE I.

Mineral	Habit	Cleavage	Ref. Indices	Character
Olivine.	Euhedral or corroded.	{010} and {100} occasionally conspicuous.	$\alpha = 1{\cdot}660$	2V = 90°
Melilite (margins).	Tabular.		$\omega = 1{\cdot}660$ $\epsilon = 1{\cdot}655$	Negative.
Apatite.	Prismatic.	Basal.	$\omega = 1{\cdot}640$ $\epsilon < 1{\cdot}640$	Negative.
Nepheline (rare)	Tabular.	Prismatic.	*ca.* 1·536	Negative.
(?) *Ashcroftine.*	Fibrous radial.	Across the fibres.	α and β *ca.* 1·535 $\gamma = 1{\cdot}544$	Length fast.
Leucite.	Anhedral. Polysynthetic twinning.	(Irregular cracks.)	Just above 1·506	Positive.
Phillipsite.	Clusters and radial spherulites.	Prismatic (Irregular cracks).	$\alpha = 1{\cdot}497$ $\gamma = 1{\cdot}503$	Positive.
Natrolite.	Interlacing prismoids.	Prismatic.	$\alpha = 1{\cdot}478$ $\gamma = 1{\cdot}490$	Positive.
Fluorite.	(Cleavage flake.)	Octahedral.	Well below 1·444	Isotropic.

In section (Plate X, Fig. 1) the minerals found include those listed in the above table, together with perovskite and magnetite and possibly a little monticellite; in addition there is an ore-sprinkled mesostasis or groundmass of obscure cryptocrystalline or glassy material of bright green, yellowish green, or brownish colour. No augite has been detected except in reaction rims surrounding the xenocrysts of quartz which occur in some of the tuffs and bombs from the crater rim. A micrometric measurement of the mode, of a typical specimen, as complete as is practicable, is recorded with the chemical analysis on page 205.

Chemically the rock is exceptionally rich in potash for a member of the olivine-melilitite group, and both in this respect and mineralogically it is a new type to which no existing rock-name can appropriately be applied. Unless it is to be referred to as a potash-rich pyroxene-free olivine-melilitite or a leucite-poor (or leucite-free) silica-poor venanzite, a specific name must be given to it. The term *katungite* is therefore proposed, after the name of the extinct volcano of which it was the sole product.

Melilite occurs in tabular crystals which are usually about 0·5 mm. square (or octagonal) by 0·1 mm. thick. Euhedral forms are characteristic, but the edges are often ragged; skeletal forms and aggregates in parallel growth are occasionally seen. In the fresh rock the mineral is nearly colourless, but on alteration a yellowish tint appears and reddish brown striations develop inwards, at right angles to the basal plane. As these increase in length, peripheral alteration to a deep brown ferruginous material spreads from the edge, until finally only an opaque brown pseudomorph remains.

Most of the melilite crystals are lightly sprinkled with inclusions of perovskite and magnetite, often beautifully euhedral, while apatite needles are invariably present, sometimes in local swarms. Throughout the Katunga lavas, whatever the size or shape of its crystals or its proportion in the rock, the melilite shows the same characteristically zoned appearance between crossed nicols. The interference colour of the interior is a deep inky blue and this passes outwards through lighter tints to a marginal zone of low, but normal, colours.

TABLE II.

Melilite, Capo di Bove, Italy.

(Analysis by H. S. Washington in A. F. Buddington, 1922, p. 83.)

	Percentages.	*Mol. Props.*	*40 per cent.*	*Atomic Proportions.*	
SiO_2	40·03	·6665	·2666	Si 18·50	Y = 30·91
Al_2O_3	5·66	·0555	·0222	Al 3·06	
Fe_2O_3	7·76	·0486	·0194	Fe''' 2·70	
FeO	·40	·0056	·0022	Fe'' ·16	
MgO	9·43	·2339	·0936	Mg 6·49	
CaO	32·17	·5737	·2295	Ca 15·92	X = 19·48
Na_2O	2·83	·0457	·0183	Na 2·54	
K_2O	1·72	·0183	·0073	K 1·02	
TiO_2	none	—	—	O 70·00	70·00
MnO	none	—	—	(nearly $X_{20}Y_{30}O_{70}$)	
	100·00				

Optical Properties.—Cores have anomalous berlin-blue interference colours. Refractive index = 1·654. Margins have normal low colours. $\omega = 1{\cdot}666$; $\epsilon = 1{\cdot}661$. Negative.

The melilite is clearly a ferric variety of unusual composition. Comparison of the mode and norm of the analysed rock indicates that the melilite must be rich in the constituents of åkermanite and that it cannot contain those of gehlenite in the proportion (about 60 per cent) suggested by comparison of its optical properties with those of the gehlenite-åkermanite series (Ferguson and Buddington, 1920, p. 136). An attempt was made to find an actual analysis of melilite which would permit an approximate calculation to be made of the mineral composition of katungite. The only satisfactory result was that based on the analysis quoted above. When 40 per cent (the modal amount) of melilite of this composition is subtracted from the composition of the rock, the balance corresponds reasonably well with the rest of the mode (see page 205).

Buddington points out (p. 84) that this analysis cannot be recalculated in terms of åkermanite, gehlenite, and sarcolites without very considerable discrepancies. Winchell (1924), however, recognized that all melilites closely approximate to R_5O_7, where R includes silicon and all the bases. Berman (1929) has slightly modified this interpretation; he shows that the analytical data for twenty-three melilites nearly fit the formula $X_2Y_3O_7$, where $X = Ca + Na + K$ and $Y = Mg + Fe'' + Al + Fe''' + Si$. The above analysis is not one of those considered by Berman and it is therefore of interest to find that it, too, nearly fits his formula, as shown in Table II. However, the analysis cannot be recalculated into the theoretical molecules adopted by Berman (åkermanite; gehlenite; soda melilite, $Na_2Si_3O_7$; and sub-melilite, $CaSi_3O_7$). The following alternative recalculation gives a more satisfactory result:—

		Molecules per cent.
Åkermanite	$Ca_2\ (Mg,\ Fe'')\ Si_2\ O_7$	66·83
Alkali-ferric	$\left\{\begin{array}{l}(Na,\ K)_2\ (Al,\ Fe''')_2\ SiO_7\end{array}\right.$	17·90
Gehlenite	$Ca_2\ Fe_2'''\ SiO_7$	11·05
Balance	$Ca\ Si_{5\cdot5}\ O_{7\cdot9}$	4·22

Olivine ranges in size from the phenocrysts (3 mm.) down to grains of minute size in the groundmass. Polysomatic aggregates also occur, always made up of small rounded grains. Although some of the crystals are sharply euhedral (Plate X, Fig. 1), many examples are corroded: sometimes intricately, sometimes at one end or on one face only. Penetration by tongues of groundmass crowded with grains of magnetite and perovskite is common, and sometimes complete, resulting in the apparent separation of corroded fragments which retain optical continuity. The fragmentary and lop-sided appearance of many of the crystals is probably due to this type of disintegration, followed by floating apart of the relics. From the ends of the invasive tongues strings of sporadic inclusions of magnetite can often be traced. Perovskite never occurs as an inclusion in olivine except in the immediate vicinity of such tongues. Many of the olivine crystals are traversed by sinuous trains of gas bubbles exactly like those in the peridotite xenoliths of the Bufumbira lavas (Holmes and Harwood, 1937, p. 21). In katungite they are undoubtedly of earlier formation than the groundmass tongues, since the latter sometimes cut through them.

In some specimens (e.g. C. 4414) the olivine is outlined by a narrow peripheral zone in optical continuity with the rest of the crystal, but differing from it in having a very much lower birefringence. This may be monticellite (cf. Bowen, 1922, p. 3).

Leucite has been detected in only a few of the slides. It occurs in irregular lobate patches and aggregates of small rounded forms. It is not always easy to distinguish it from basal sections of melilite, except when its lower refractive index or polysynthetic twinning can be recognized. Inclusions are rare, other than occasional needles of apatite and blebs of glass. Some examples contain nests of a radial greenish yellow mineral that has a lower refractive index than leucite and a higher birefringence; it is probably iron-stained natrolite.

Phillipsite occurs as vesicular infillings, often drawn out into long irregular forms, and also as spherulitic linings to vesicles mainly occupied by natrolite. Within the latter it also forms bleb-like inclusions which are seen between crossed nicols to be radial spherulites. The extinction angle Z ∧ a is 20°.

A mineral that may be *ashcroftine* (formerly known as kalithomsonite; *see* Hey and Bannister, 1933) has been detected as thin vein-like streaks and small vesicular infillings. Its fibrous radial habit distinguish it from nepheline, which it resembles in refractive index.

Nepheline is extremely rare and has been found only in occasional lath-shaped forms. It may be kaliophilite, but the refractive index is more characteristic of a potash-rich nepheline (Bowen and Ellestad, 1936, p. 365).

Natrolite is common in specimens from the neighbourhood of the sources of the flows, where it occurs as vesicular infillings in much the same way as phillipsite, by which it is often accompanied.

Apatite is a conspicuous accessory, occurring in minute needles in melilite and the groundmass, and, much more rarely, in leucite and olivine. Prisms of a larger order of size (0·5 × 0·05 mm.) are also present, but sparingly.

Fluorite has not been found in any of the slides, but cleavage flakes (the largest being 0·3 × 0·1 mm.) were found during the examination of one of the samples of crushed material (C. 3947 from the eastern flow) with refractive-index liquids.

Perovskite is conspicuously and uniformly distributed as golden brown octahedra, twinned aggregates and irregular grains (up to 0·2 mm.). It is slightly birefringent and positive in character.

Magnetite occurs abundantly in the groundmass as minute, evenly distributed grains. In some slides occasional microporphyritic grains occur (0·6 mm.), all of which show intricately corroded margins.

Variations in the Flows.—In the western flow natrolite is most abundant near the source (C. 4411–4412). Away from the source phillipsite increases in amount and natrolite practically dies out about half-way down the flow, at which point leucite begins to come in (C. 4407–4408). The proportion of crystals to groundmass increases from source to foot, but at the same time the size of the melilite crystals decreases. Near the source the groundmass is altered to an opaque grey or greenish grey substance.

The eastern flow shows similar variations from source to foot, but there appear to be certain minor differences. Melilite tends to be more ragged in form and somewhat larger in size, and a greyish yellow tint is often characteristic. One specimen (C. 3946) from near the end of the flow illustrates various stages in the alteration of melilite to reddish brown pseudomorphs. Near the source the proportion of phillipsite to natrolite is higher than at the head of the western flow.

So far as the specimens are representative, it would appear that the first part of the katungite magma to be extruded was poorer in soda than the latest portions to reach the surface. This inference from the distribution of natrolite has been confirmed by analyses for alkalies alone (see page 208).

TABLE III.

Composition of Katungite, Western Flow, C. 4407, Katunga, Uganda.

	Percentages.	*Molecular Proportions.*
SiO_2	35·37	·5889
Al_2O_3	6·50	·0638
Fe_2O_3	7·23	·0453
FeO	5·00	·0696
MgO	14·08	·3492
CaO	16·79	·2994
Na_2O	1·32	·0213
K_2O	4·09	·0434
H_2O +	2·78	·1543
H_2O −	1·15	—
CO_2	·09	·0021
ZrO_2	none	—
TiO_2	3·87	·0484
P_2O_5	·74	·0052
Cl	·02	·0006
F	·16	·0084
S	·35	·0109
Cr_2O_3	·01	·0001
V_2O_3	·03	·0002
NiO	·19	·0025
MnO	·24	·0034
BaO	·25	·0016
SrO	·04	·0004
CuO	·06	·0008
Li_2O	none	—
	100·36	
Less O	·24	
	100·12	

Analyst: A. W. Groves.

Calculated Mineral Composition.		
Melilite (see p. 202)		40·00
Leucite		15·75
Ca_2SiO_4		·17
Olivine Mg_2SiO_4	17·98	22·33
Olivine Fe_2SiO_4	4·35	
Perovskite		6·58
Magnetite		6·02
Pyrite		·65
Nephelite		·85
Apatite		1·75
Fluorite		·24
Calcite		·21
Excess Al_2O_3		·27
Excess SiO_2		1·34
Water		3·93
		100·09

Mode Percentages by Volume.	
Melilite	40·0
Leucite and Zeolites	10·2
Olivine	21·3
Perovskite	7·2
Groundmass (including magnetite)	22·3
	101·0

Specific Gravity = 3·11

II. CHEMICAL COMPOSITION.

Dr. Groves's detailed analysis of a typical fresh specimen of leucite-bearing katungite, poor in natrolite and free from xenolithic material, is given in Table III. The norm of this rock departs so widely from the mode as to be of little interest. The abnormality of the "norm" is at once made evident by the fact that the molecular proportion of $Na_2O + K_2O$ is greater than that of Al_2O_3, a fact which suggests that the melilite must be an alkali-ferric variety. The mineral composition has therefore been calculated on the assumption that the melilite has the same composition as that quoted in Table II. All the remaining potash has then been allotted to leucite, and all the

TiO_2 to perovskite. Comparison of the results with the mode leads to the following inferences :—

(*a*) Since there is more modal perovskite than calculated, the black ore grains must consist essentially of magnetite, not ilmenite. (*b*) Since there is more calculated leucite than modal leucite + zeolites, the mesostasis must be relatively rich in potash. The alternative interpretation, that the excess potash is in the melilite is inherently improbable, and, moreover, there is independent evidence from the metasomatism of quartz xenoliths that the magma of katungite gave out emanations rich in potash and alumina (see pp. 213–214).

Katungite tuffs with lapilli and ejected blocks are widely distributed in the volcanic fields flanking Ruwenzori (Holmes and Harwood, 1932, pp. 395, 402, and 413). New analyses, made by Dr. H. F. Harwood of katungite lapilli (E) and of an ejected block of biotite-katungite (F) are given in Table IV. Like the type katungite, these show dominance of potash over soda and an assemblage of minor constituents which is characteristic of the alkali ultrabasic rocks of the region and of olivine-melilite rocks in general (see Holmes and Harwood, 1932, p. 419 ; and 1937, p. 48, for geochemical discussion).

Among plutonic types the closest analogue of katungite is biotite-pyroxenite, the average composition of which is given under C in Table IV. The chief difference is the lower silica percentage of katungite, but there are correlated minor differences which, taken together, are of great petrogenetic significance (see page 217). An interesting heteromorph of the katungite–biotite-pyroxenite series is the melanite-ouachitite of Turja (B in Table IV). This rock consists essentially of biotite and melanite (together making over 80 per cent of the rock) with interstitial analcite or sodalite, calcite, apatite, pectolite, and ore grains. It is an end product of the melanite-biotite-pyroxenites, of which several examples are known.

Alkali Variation.—Analyses of three other specimens of katungite have been made for alkalies alone by Messrs. W. H. Herdsman. The figures are listed below, together with those for the fully analysed rock and those for other examples of katungite from Katwe and Kikorongo. (Table V, p. 208.)

The results for Katunga confirm the inference, already drawn from the observed distribution of natrolite, that the later portions of the katungite lava to be extruded were richer in soda than the earlier.

III. CLASSIFICATION.

There is clearly need to systematize the classification and nomenclature of the group of rocks characterized by essential olivine and melilite. The mineral compositions of the various types now recognized are summarized in Table VI. Chemical analyses of all these types (except bizardite) will be found in Tröger's *Kompendium*

TABLE IV.

Analyses of Katungite and Related Rocks.

	A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*	*H.*
SiO_2 .	41·43	37·31	44·48	35·37	35·51	37·93	33·37	36·95
Al_2O_3 .	9·80	8·81	7·97	6·50	6·83	6·59	7·56	7·85
Fe_2O_3 .	3·28	8·42	4·07	7·23	9·68	6·81	5·33	4·78
FeO .	5·15	2·60	5·04	5·00	2·70	4·37	6·39	8·70
MgO .	13·40	11·02	14·98	14·08	11·67	14·54	12·50	15·87
CaO .	16·62	16·23	14·84	16·79	16·00	15·23	20·25	13·60
Na_2O .	1·64	1·66	·80	1·32	1·56	·88	2·03	2·32
K_2O .	7·40	4·46	3·70	4·09	3·30	2·65	3·06	2·04
$H_2O +$.	1·11	2·17	1·01	2·78	3·11	3·38	3·06	1·64
$H_2O -$.	—	·10	·66	1·15	1·31	1·42	·10	·49
CO_2 .	—	2·36	·33	·09	1·47	·50	1·56	·06
ZrO_2 .	—	—	—	none	none	—	·03	·04
TiO_2 .	·29	3·33	2·10	3·87	4·88	4·12	2·56	4·59
P_2O_5 .	none	1·33	·66	·74	1·18	1·03	1·50	·83
Cl . .	—	—	·06	·02	tr.	·01	·05	tr.
F . .	—	—	·22	·16	·27	·16	·18	·05
S . .	—	·10	·06	·35	—	—	·29	none
SO_3 .	—	—	—	—	·13	·06	·10	—
Cr_2O_3 .	—	none	·05	·01	·02	·05	·08	·03
V_2O_3 .	—	—	·06	·03	·04	·02	—	·04
NiO .	—	—	·05	·19	·02	·03	—	·04
MnO .	—	—	·16	·24	·22	·18	·20	·20
BaO .	—	·19	·25	·25	·27	·30	·32	·09
SrO .	—	—	·10	·04	·24	·25	·14	·04
CuO .	—	—	·07	·06	—	—	—	—
Li_2O .	—	—	tr.	none	tr.	tr.	·03	tr.
	100·12	100·09	100·72	100·36	100·41	100·51	100·76	100·25
Less O	—	·04	·13	·24	·11	·07	·26	·02
	100·12	100·05	100·59	100·12	100·30	100·44	100·50	100·23

A.—Venanzite, Pian di Celle, near San Venanzo, Umbria, Italy. Analyst: H. Rosenbusch. (V. Sabatini, 1899, p. 12; Washington's Tables, p. 717.)

B.—Melanite-ouachitite. Dyke cutting ijolite, south end of Turja, Kola Peninsula. Analyst: E. H. Kranck. (E. H. Kranck, *Fennia*, 51, No. 5, 1928, p. 68.)

C.—Average of 16 analyses of biotite-pyroxenite from Uganda (2); Italy (6); Burma; Malverns; Newry; Loch Ailsh; Rossland (2); Libby Stock (Montana); Raniganj (India). For detailed analyses see Doris Reynolds, 1935, pp. 450–451; and A. Holmes and H. F. Harwood, 1937, Chapter iii.

D.—Katungite. Lava flow, Katunga, Western Ankole, Uganda. Analyst: A. W. Groves.

E.—Katungite. Lapilli separated from katungite tuff, G. 21, Katwe Crater, near shore, north-east corner of Lake Edward, Uganda. New analysis by H. F. Harwood.

F.—Biotite-katungite. Ejected block, G. 56, Katwe Crater. New analysis by H. F. Harwood. Another specimen gave $Na_2O = 1·07$; $K_2O = 3·63$ (A. Holmes and H. F. Harwood, 1932, p. 405).

G.—Alnöite, Stornäset, Island of Alnö, Sweden. Analyst: M. Bendig. (E. Tröger, 1934, p. 171; *Kompendium*, p. 301, No. 746, Rare earths, ·07).

H.—Leucitic olivine-melilitite, Spiegel River Farm, Heidelberg, Cape Province, South Africa. Analyst: L. S. Theobald. (A. Holmes, 1937, p. 393.)

(as indicated in Table VI) or in Table IV. The criteria which appear to be of most value for purposes of classification and petrogenetic discussion are :—

(*a*) The presence or absence of pyroxene and/or biotite.

(*b*) The relative proportions of potash and soda, conveniently expressed by the potash-ratio, 100 $K_2O/(Na_2O + K_2O)$.

TABLE V.

Specimen No. and Locality	K_2O	Na_2O	$\frac{100\ K_2O}{K_2O + Na_2O}$
KATUNGA—			
C. 3949. Near source, Eastern Flow .	3·66	2·65	58
C. 4412. Near source, Western Flow .	3·55	2·96	54
C. 4411. 50 ft. below source Western Flow	3·84	2·91	57
C. 4407. Near end of Western Flow .	4·09	1·32	75
KATWE—			
G. 56. Biotite-katungite, Table IV, F .	2·65	·88	75
G. 56. Do. (Holmes and Harwood, 1932, p. 405)	3·63	1·07	77
G. 21. Lapilli, Table IV, E . . .	3·30	1·56	68
KIKORONGO—			
D.G.S. 471. Lapilli (Holmes and Harwood, 1932, p. 396)	2·87	2·14	57

Adopting these criteria, the rocks already described can be arranged as in Table VII.

Some of the names in Tables VI and VII might conveniently be dropped. *Cecilite*, for example, is unnecessary, and *vesecite* can be adequately described as monticellite-polzenite. *Polzenite* has had a " bad press ", but there is, nevertheless, a clear case for its adoption. The term *modlibovite* becomes unnecessary, as the type it connotes is simply lazurite-polzenite.

Stansfield's term *bizardite*, for " nepheline-bearing alnöite " (1923, p. 551) requires closer definition. Alnöite contains more potash than soda (Brögger, 1921, p. 323) and, even so, is sometimes nepheline-bearing. Bizardite is needed only for alnöitic rocks with more soda than potash and/or sufficient nepheline to ensure this distinction from alnöite. The nepheline-hauyne-alnöite described by Ross (1926) has a potash-ratio of 40 and is therefore better named hauyne-bizardite.

Luhite is not calcite-polzenite, as it is generally regarded, since it contains about 20 per cent of pyroxene ; the term could well be dropped in favour of calcite-bizardite.

Stansfield's suggestion (1923, p. 551) " that the prefix 'biotite-' to the rock name in this group of rocks should connote the existence of biotite as the *sole* ferro-magnesian constituent " is not acceptable. As an example, he suggests that bergalite (biotite, melilite, hauyne,

TABLE VI.

MINERAL COMPOSITION OF OLIVINE-AND-MELILITE-BEARING ROCKS.

Tröger's *Kompendium* No.	Rock-types and Localities	Melilite	Olivine	Monticellite	Pyroxene	Nepheline	Hauyne, etc.	Biotite	Leucite	Mesostasis	Perovskite	Opaque Ores	Calcite
	KATUNGITE.												
	Katunga, Ankole, Uganda .	40	22	(?)	—	(?)	—	—	25		7	6	a
	Biotite-katungite, Katwe, Uganda	x	x	—	—	—	—	x	—	x	x	x	a
	VENANZITE.												
672	San Venanzo, Umbria, Italy . = *Leucite-rich katungite.*	47	17	—	—	—	—	4	30	—	2		a
	POLZENITE (Polzen, N. Bohemia).												
664	Modlibovite, Modlibove, Polzen . . . . = *Lazurite-polzenite.*	34	22	—	—	16		22	—	—	16		a
663	Vesecite, Vesec, Polzen . = *Monticellite-polzenite.*	33	23	10	—	14		12	—	—	8		a
	ALNÖITE.												
746	Alnö, Sweden . . .	33	5	—	17	a	a	30	—	—	12		3
748	Monticellite-alnöite, Montreal	25	30	10	6	—	—	20	—	—	9		a
		3	30	25	10	—	—	30	—	—	7		6
667	Nepheline-hauyne-alnöite, Montana . . . = *Hauyne-bizardite.*	17	35	—	5	5	11	16	—	5	—	6	—
	BIZARDITE.												
665	Isle Bizard, Montreal .	x	x	—	x	x	—	x	—	—	x	x	a
[illegible]	Luhite, Luh, Polzen, Bohemia . . . = *Calcite-bizardite.*	22	15	—	20	11	5	8	—	—	5		13
	OLIVINE-MELILITITE.												
750	Hochbohl, Swabian Alb .	44	23	—	19	6	—	a	—	—	4	4	a
	CECILITE.												
671	Cecilia, Capo di Bove, Italy . = *Melilite-olivine-leucitite.*	12	7	—	23	—	—	—	42		5		

a = accessory amounts.
Apatite is a constant accessory of all the above rocks.

nepheline) could be called "biotite-polzenite". But polzenite contains essential olivine and the term *polzenite* should not have one meaning when it stands alone or has a prefix other than biotite-, and another meaning when the prefix *is* biotite-.

It is as important to discriminate between pyroxene and pyroxene-free members of this alkali ultrabasic group of rocks as it is to distinguish olivine-basalt from basalt. Hitherto, the known pyroxene-free members have been called *polzenite* (with soda feldspathoids) and *venanzite* (with abundant leucite). The rocks now called *katungite* bridge the gap between these two types. But clearly it would be highly misleading to describe katungite as a variety of venanzite. The latter is the end-member of the series, with an abundance of leucite and a potash content of an altogether higher order than that of any katungite. The mineralogical and chemical significance of the term *venanzite* would be entirely lost if the meaning were to be so extended as to include katungite. On the other hand, had venanzite not already been so named, it could be adequately referred to as leucite-rich katungite.

In the light of the above survey, and with a view to making the new term *katungite* as widely applicable as possible, the following definition is framed. *Katungite* is an alkali ultrabasic rock with more potash than soda, the essential minerals being melilite and olivine ; the potash may be present in glass, zeolites, potash-rich nepheline, kaliophilite, leucite, or biotite ; special varieties may be distinguished by appropriate mineralogical prefixes, e.g. leucite-katungite, biotite-katungite, leucitic biotite-katungite.

Table VII.

Classification of Melilite–Olivine Rocks.

<table>
<tr><td colspan="2">$\frac{100\ K_2O}{Na_2O + K_2O}$</td><td colspan="4">. . . 10 . . . 20 . . . 30 . . . 40 . . . 50 . . . 60 . . . 70 . . . 80 . . . 90 . .</td><td>$\frac{100\ K_2O}{Na_2O + K_2}$</td></tr>
<tr><td rowspan="3">Pyroxene Essential</td><td colspan="2">Melilite-
Olivine-Nephelinite</td><td>Melilite-leucite-olivine-nephelinite
Melilite-nepheline-olivine-leucitite</td><td colspan="2">Melilite-
Olivine-Leucitite
Cecilite (80)</td><td rowspan="3">Pyroxene Essential</td></tr>
<tr><td colspan="5">Olivine-Melilitite
(30–40)
Nepheline-olivine-melilitite (19–29)
Leucitic Olivine-melilitite (43–58)</td></tr>
<tr><td rowspan="2">Biotite Essential</td><td>Bizardite</td><td colspan="2">Alnöite
(54–80)
(Average, 66)</td><td>Biotite</td></tr>
<tr><td>Soda Felspathoids</td><td>Polzenite
(30–40)
Modlibovite
Vesecite</td><td>Katungite
(54–75)
Biotite-katungite
(75–77)</td><td>Venanzite =
Leucite-rich
Katungite
(82)</td><td colspan="2">Leucite and/or Biotite</td></tr>
</table>

Ross (1926, p. 222) speaks of " the obscurity that may be introduced into rock classification by a multiplicity of names ". While I agree that certain names have been carelessly defined and unnecessarily introduced, I must confess that my own sympathies are with those who, like Lacroix, Brögger, and Washington, have felt it desirable to coin new names in the interests of precision. Any obscurity that they and other petrologists may have introduced need not be more than temporary and is, in any case, of trifling importance compared with the really disastrous ambiguities that befog much petrological literature as a result of misuse of existing terms and extensions of old meanings. Better a new name than an old one wrongly applied.

Bowen (1922, p. 8) has also had his little grumble about " the meaningless names based on locality that are being coined daily "—a double exaggeration that need not be taken seriously since the terms are not meaningless and are at present being added to at the rate of about ten a year. Now that Tröger's invaluable *Kompendium* is available, petrologists have no longer any excuse for failing to understand the language of their subject or for failing to use it properly in their own writings. Palaeontologists, zoologists, and botanists have to cope with hundreds of thousands of names ; surely petrologists need not despair because they have provided each other with a single thousand. Shand (1935, p. 383) has also complained that to him most of the locality names are " just sounds without sense ". But new names are not introduced in order that everyone will remember them, nor are they " based on nothing more than personal whim ". Any petrologist who fails to master the nomenclature of the rock suite he happens to be investigating is professionally lazy and is unlikely to contribute usefully towards the solution of petrological problems. Shand's defeatist attitude is the more remarkable because no one could possibly accuse him of professional laziness. It is a dangerous illusion to imagine that the problems of petrology can ever be solved without a detailed and adequate nomenclature in terms of which those problems can be accurately and unambiguously stated.

TABLE VIII.

TYPES WITH OLIVINE		TYPES WITHOUT OLIVINE	
" Locality " Name	" Rational " Name	" Locality " Name	" Rational " Name
Bizardite	Olpybinemelite		
Hauyne-bizardite	Olpybihanemelite		
Luhite	Olpybinecamelite		
Alnöite	Olpybimelite	Coppaelite	Phlodimelite
Polzenite	Olbihanemelite	Bergalite	Bihanemelite
		Okaite	Bihamelite
		Turjaite	Binemelite
Modlibovite	Olbilanemelite		
Vesecite	Olmobihanemelite		
Leucite-katungite	Ollemelite		
Biotite-katungite	Olbimelite or Ollebimelite	Biotite-melilite rock	Bimelite
Venanzite	Ollephlomelite		
		Vesbite	Aegimelleite
		Uncompahgrite	Dimelite

The only really practicable alternative to locality names that has so far been proposed is that of Beliankin (1929). It has already been applied to certain rocks in the U.S.S.R., but has received little or no attention elsewhere. Following Beliankin's system of building up names from the first syllables or letters of the names of the essential minerals (e.g. *mel*ilite, *ol*ivine, *py*roxene, *bi*otite, *le*ucite, *ne*pheline), the melilite rocks under discussion would be designated by terms such as those in Table VIII.

In order that the reader may not be unduly prejudiced, it must be pointed out that some of the above samples present the "rational" system of nomenclature in its most unfavourable light. My own preference for locality names is based on the fact that, when they are familiar, they suggest specific associations which range in interest and significance far beyond a mere catalogue of minerals. However, I see no reason why both sets of terms should not sometimes be used, especially when the locality name is likely to be generally unfamiliar. When the name *uncompahgrite*, for example, is first mentioned in a petrological paper, it might well be followed by (*dimelite*), as a reminder to the reader.

A partial weakness in the Beliankin system, as constituted at present, is the lack of any provision for dealing with glassy rocks. Some varieties of katungite would have to be termed *potassic vitrophyric olmelite*. Here the advantage clearly remains with the locality name.

IV. Tuffs and Bombs.

As observed by Combe, *tuffs* are exposed only along the northern part of the crater rim. The two specimens from here are crumbly aggregates, largely composed of lapilli, those in C. 3921 averaging about 5 mm. in diameter, while those in C. 3920 are much smaller. Associated with lapilli are euhedral and broken crystals of olivine, identical in characters with those of katungite and of all sizes up to 3 mm. long; bits of fresh or transfused biotite- and muscovite-schists; coarsely crystalline alkali felspar, probably derived from the pegmatite veins which occur sporadically in the ejected blocks of the Igara Schist Series that lie about the slopes; quartz aggregates, some of which resemble vein-quartz, more or less transfused as described below; and, in one section, biotite-pyroxenite.

The *lapilli* consist of fine-grained katungite containing a high proportion of an opaque, nearly black, groundmass. Melilite is commonly altered to a grey opaque substance and may be of the same order of size as in the lavas or very much smaller. Olivine remains perfectly fresh and, though much of it is fragmental, some of the crystals are as large as any in the lavas. Perovskite is identical in colour, forms, and proportion with that of the lavas. Vesicular infillings of phillipsite are seen occasionally, but no natrolite has been detected.

In the section showing a fragment of biotite-pyroxenite the lapilli consist of very fine-grained katungite containing corroded xenocrysts of biotite and augite (Plate X, Fig. 2), obviously derived from biotite-pyroxenite of the same type as the xenolith. The augite is mostly of a pale green variety channelled with trains of gas bubbles exactly like that of the ejected blocks of biotite-pyroxenite, pyroxenite and peridotite from the Bufumbira volcanoes (Holmes and Harwood, 1937, p. 21). Some of the fragments, however, are of bright green colour and more closely resemble the hedenbergitic pyroxene described from the biotite-pyroxenite of Kikorongo (Holmes and Harwood, 1932, p. 397). The biotite is a bright pleochroic variety like the earlier biotite of the Bufumbira examples. It has curved and contorted cleavages and frequently the latter have been prized apart by tongues of zeolitic or groundmass material.

Table IX.

	A. *Glass and Quartz.*	*B.* *Glass alone.*	*C.* *Material introduced into Quartz.*
SiO_2	86·35	74·51	—
Al_2O_3	5·27	9·78	38·05
Fe_2O_3	·03	·06	·23
FeO	·19	·35	1·36
MgO	·87	1·61	6·26
CaO	·64	1·19	4·63
Na_2O	·49	·91	3·54
K_2O	3·32	6·16	23·97
H_2O+	2·43	4·51	17·55
H_2O-	·25	·46	—
CO_2	·13	·24	·93
TiO_2	·09	·17	·66
P_2O_5	none	none	—
MnO	·14	·26	1·01
	100·20	100·21	98·19

A.—Mixture of glass (54 per cent. by weight) and quartz from a transfused vein-quartz xenolith in a bomb of katungite (C. 4418) from the north face of Katunga, western Ankole, Uganda. *Microchemical analysis* by Friedrich Hecht, University of Vienna.

B.—Composition of glass alone, calculated from A.

C.—Composition of material introduced into quartz from the magma.

Bombs are represented by six specimens collected from the north face of Katunga above the source of the western flow. They are all phillipsite-bearing varieties of katungite, practically free from natrolite. Apart from the occurrence of xenoliths in some of them, they range in type from fine-grained varieties like the groundmass-rich lapilli to crystal-rich varieties like the analysed specimen, C. 4407, from the western flow. Three of the bombs, however, are of special interest because of the occurrence in them of xenoliths of biotite- and muscovite-schists; more or less transfused vein-quartz; and fragments of alkali felspar. The source of these is clearly the Igara Schist Series and the veins of quartz and pegmatite seen to be associated with the schists in the ejected blocks around the crater. Inclusions of lapilli of much altered katungite also occur in the bombs, and some of these lapilli also contain xenolithic relics of the three kinds just mentioned.

The *transfused vein-quartz* contains narrow vein-like channels of nearly colourless glass which form a more or less uniformly distributed network (for figure, see Holmes, 1936, plate xiii, fig. 3). The channels follow the intergranular boundaries for the most part, but they also traverse individual grains, sometimes sharply cutting through them, sometimes ending abruptly as blind, lobe-like ducts. The glass is clearly a metasomatic replacement of quartz. In some of the wider channels a composite structure can be detected: an inner channel of refractive index 1·486 being sharply separated from marginal zones, adjacent to quartz, with a refractive index of 1·476. The refractive index of fused silica is 1·458.

In order to ascertain what constituents have entered the quartz from the magmatic material of the lava, a microchemical analysis of a separated product consisting of 54 per cent of glass and 46 per cent of quartz was made by Dr. F. Hecht, with the results listed under A in Table IX. The data show that the chief materials introduced were alumina, potash, and water. Compared with the transfusion of quartzite in Colonsay (Doris Reynolds, 1936, p. 396), the main chemical difference is the relatively feeble diffusion of soda from katungite. For further details and other examples of quartz transfusion in Bufumbira lavas reference may be made to a recent paper on the subject (Holmes, 1936).

V. PETROGENESIS.

In the Toro-Ankole volcanic fields the evidence, wherever it is complete, shows that the succession of rock-types was: (*a*) *biotite-pyroxenite* and its associates, e.g. glimmerite, pyroxenite, and peridotite; (*b*) *katungite*, locally grading to alnöite (mainly tuffs with abundant lapilli); (*c*) *leucitic rocks*, such as ugandite,[1] augite-rich ugandite, olivine-leucitite, and leucitite (Holmes and Harwood, 1932, p. 418). In Swabia biotite-pyroxenite and varieties respectively rich in olivine, hornblende, ilmenite, and apatite occur in the olivine-melilitite tuffs of the "embryo-volcanoes" (Schwarz, 1905, pp. 264–8). The minerals of a similar suite of rocks occur as xenocrysts and xenolithic aggregates in the olivine-melilitite necks of the Sutherland district of the Cape Province, South Africa.

Katunga is exceptional, for the Toro-Ankole fields, in having massive flows of katungite lava with few tuffs and only traces in the latter of biotite-pyroxenite. The regional association of types is there, however, and it is therefore important to consider the chemical differences between the two related rock types, biotite-pyroxenite and katungite. Reference to Table IV shows that in order to transform biotite-pyroxenite into katungite it would be necessary to add material very poor in silica and relatively rich in Fe_2O_3, TiO_2, CaO, P_2O_5, Na_2O, K_2O, H_2O, and CO_2.[1] This is by no means so haphazard an assemblage of constituents as at first sight it may appear to be.

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[1] *Ugandite* is a term recently proposed for melanocratic olivine-leucitite (melano-olpyleite). The rocks formerly described as potash-ankaratrite are now termed *augite-rich ugandite* (Holmes and Harwood, 1937, p. 11).

In discussing the origin of the Uganda biotite-pyroxenites I have pointed out (Holmes and Harwood, 1937, p. 56) that biotite, at least in part, is a replacement of the earlier minerals, olivine and pyroxene, of peridotite. Biotite is replaced in turn by titan-biotite and melanite, with notable increase in the rock of apatite. In the biotite-pyroxenite of Kikorongo melanite replaces biotite and pyroxene; ilmenite replaces all the earlier minerals; sphene replaces ilmenite; and apatite and occasionally calcite increase in amount. The post-peridotite introduction of constituents is therefore K_2O, Al_2O_3, Fe_2O_3, CaO, TiO_2, Na_2O, P_2O_5, with H_2O and CO_2. Thus, amongst the biotite-pyroxenites themselves there is evidence of addition of the same assemblage of constituents as that chemically necessary to convert biotite-pyroxenite into katungite.

Summarizing the genetic relationships of the minerals of the monticellite-alnöite of Isle Cadieux, near Montreal, Bowen (1922, p. 11) writes: "The mass originally consisted of chrysolite and augite, nearly completely consolidated as such. It was then acted upon with falling temperature by an alkalic liquid (magma) which was, in part at least, its own interstitial liquid, and as a result of this action the other minerals, biotite, monticellite, melilite, perovskite, apatite, and marialite were formed." The evidence of replacement is complete and the analyses given by Bowen show that the material introduced was poor in silica and rich in K_2O, Na_2O, Al_2O_3, CaO, TiO_2, P_2O_5, H_2O, and CO_2. Where replacement by the addition of these constituents was more advanced, seams of melilite-biotite rock were formed. Bowen notes that in these seams "monticellite is corroded by biotite and melilite in much the same manner as are the original minerals in the same mass. The monticellite is, then, to be regarded as an intermediate step in the replacement of augite and chrysolite by melilite and biotite."

Bowen makes it clear that the reactions leading to the formation of the melilite rocks of Isle Cadieux involved desilication of pre-existing material having the composition of augite-peridotite. The desilicating agent was, he thinks, essentially a liquid, rich in the constituents of nepheline and also containing potash and water, and probably largely interstitial; a liquid which, after modification by the reactions, is thought by Bowen to have passed on to form dykes of analcite-bearing rocks elsewhere. Ross (1926, p. 225) points out that in the case of the Winnett intrusion the alkali desilicating liquid was probably "forced into the partly crystalline rock from deeper seated material that was undergoing crystallization." Scheumann (1922) and Stansfield (1923, p. 448) conclude that addition of lime is also a necessary factor and they both ascribe such addition to limestone assimilation. Ross (1926, p. 226) shows that the limestone-assimilation hypothesis is not applicable to the Winnett rock and expresses doubt as to its value for other localities; it is certainly out of the question for the Uganda occurrences (Holmes and Harwood, 1932, p. 426).

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[1] Oxides are referred to here, and throughout this section, for convenience only; no implication that the material was necessarily in the form of oxides is intended.

In Uganda the lime and other constituents which were added to peridotite and biotite-pyroxenite were part of desilicating fluids which ascended from below. There is no evidence that these fluids were interstitial, or that they were derived from deep-seated material undergoing crystallization, or that their lime content was derived from limestones. Moreover, the various constituents were introduced, not as a single solution or magma, but as a sequence of successive waves of emanations, the changing composition of which can to some extent be traced from the order of formation of the replacement minerals: biotite, titan-biotite, melanite, ilmenite, sphene, and locally calcite.

The factors concerned in metasomatism, and in the related process—at a higher energy level—of syntectic magma formation,[1] may be expressed in a generalized way, as follows :—

(*a*) *Incoming emanations* (from other "active" magmas or the "substratum")

+

(*b*) *Energy* (secular; radioactive; ionic reactions; etc.)

+

(*c*) *Crustal rock material*, metasomatized, migmatized, or more or less magmatized by (*a*) and (*b*)

−

(*d*) *Outgoing emanations and associated energy* (Magmatizing agents transforming other crustal rocks into magmas; migmatizing agents generating syntectic rocks; pneumatolytic and hydrothermal fluids; volcanic gases, etc.)

In the case of biotite-pyroxenite and glimmerite the pre-existing material (*c*) is pyroxene-peridotite, metasomatized by emanations (*a*) from which the introductions consist of K_2O, Al_2O_3, some H_2O or (OH), and relatively little SiO_2, if any. The phlogopitized harzburgites and the associated phlogopite-glimmerites which occur as xenoliths in the kimberlite of diamond pipes afford a particularly clear example of the operation of this process (Holmes, 1937, p. 399).

In the case of melanite-, ilmenite-, apatite-, sphene-, and calcite-bearing biotite-pyroxenites the pre-existing material (*c*) is biotite-pyroxenite, metasomatized by emanations (*a*) from which the introductions are CaO, Fe_2O_3, TiO_2, P_2O_5, alkalies (with Na_2O in excess of K_2O), CO_2, H_2O or (OH). If more energy is available within a given place and time then magma may be generated; in the example under discussion such magma would have the composition of katungite. Adequate concentration of energy for magma formation may be brought about by (i) the highly energized state of the emanations themselves; (ii) a sufficiently high rate of introduction of the emanations; and (iii) the pre-existing rock material being at a high temperature or, in the limit, being itself already in a more or less magmatic state.

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[1] Magma formation by refusion is the limiting case, probably rare, in which only (*b*) and (*c*) are involved.

Since the Katwe suite of rocks (Holmes and Harwood, 1932, p. 403) illustrates every gradation from biotite-pyroxenites of various types through biotite-katungite to katungite, both of which must have passed through a magmatic state, it is now believed probable that the katungite of Katunga also originated by the process indicated in the foregoing paragraph. Kimberlite appears to have been formed in much the same way. The incoming emanations (*a*) were specially rich in the constituents of H_2O and CO_2. The crustal rocks (*c*), which became partly disintegrated and partly magmatized, appear to have been mainly portions of the peridotite (and eclogite) layer. The outgoing emanations (*d*) were those largely responsible for the perforation of the crust (Holmes, 1937, p. 424). Similar crustal perforation is highly characteristic of the areas of katungite and related tuffs in Western Uganda, as witnessed by the prevalence of explosion craters. The celebrated "embryo volcanoes" of Swabia provide another cogent example.

At Katunga massive lava flows appeared, suggesting that the emanations at this centre were relatively poor in H_2O and CO_2. The katungite magma, however, was not less "active" than that of neighbouring vents, since from it came the emanations, rich in K_2O and Al_2O_3, which transfused quartz xenoliths into obsidian-like glass. Similarly, in Colonsay, the outgoing emanations from a magma now largely represented by hornblendite transformed xenoliths of quartzite into syenite, and even into syenite magma (Doris Reynolds, 1936, p. 375). These examples demonstrate conclusively that the incoming emanations responsible for the generation of one kind of magma may be the outgoing emanations from another. They also suggest the great variety of magmas and rock-types that may be formed by the action of highly energized emanations on pre-existing rocks other than peridotites and biotite-pyroxenites, such as the common sedimentary rocks (including carbonate types), basaltic rocks, schists, gneisses, and granites.

ACKNOWLEDGMENTS.

I am indebted to Mr. E. J. Wayland, Director of the Geological Survey of Uganda, for the opportunity to study the lavas of Katunga, twenty-five specimens of which he sent to Durham, where they are

now housed in the Department of Geology. The cost of the chemical analysis was defrayed out of a grant from Messrs. Imperial Chemical Industries, Limited (Research Department), which is gratefully acknowledged. Thanks are also due to Dr. H. F. Harwood for permission to use two other analyses of katungite (E and F in Table IV) which form part of his contribution to our forthcoming paper on the rocks of Katwe Crater.

Finally, it is a pleasure to record that the petrogenetic conclusions expressed above do not stand alone. The observations of Dr. Doris Reynolds on the Newry Complex and in Colonsay, mine on the kimberlite suite of South Africa, and the volcanic rocks of South-West Uganda, and those we have made together during the course of joint work on which we are engaged, have all contributed to the evidence on which our gradually developing interpretation of magmatic phenomena is based.

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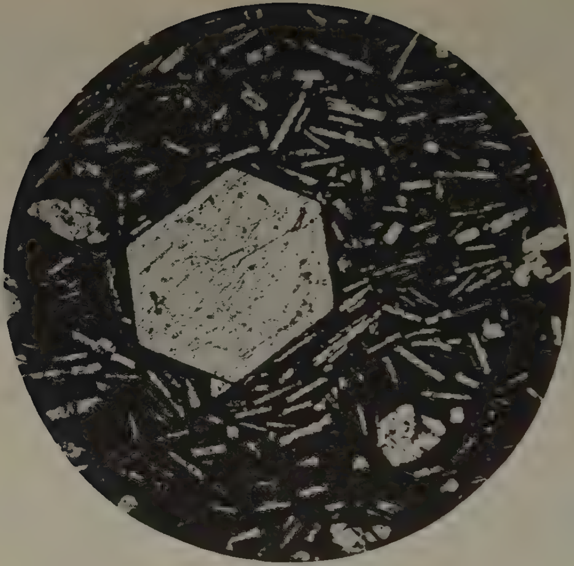

Fig. 1. × 15.

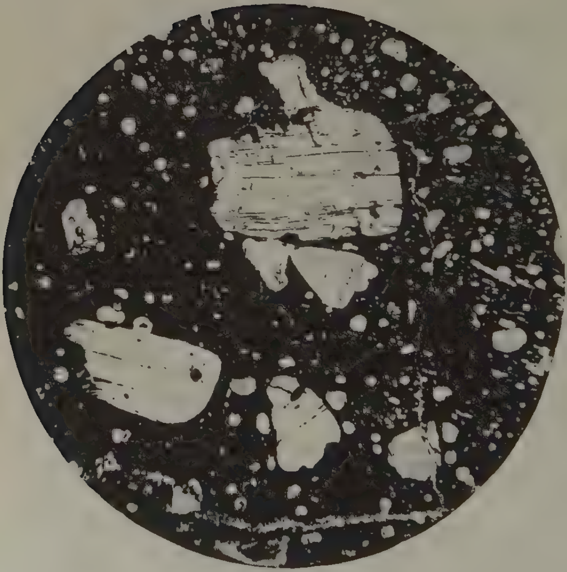

Fig. 2. × 15.

Katungite: Lava and Tuff.

Face p. 219.] *G. W. O'Neill, Photo.*

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EXPLANATION OF PLATE X.

FIG. 1.—Katungite. C. 4407. From near the end of the Western Flow, Kyamahoro River, about a mile from the point of eruption, Katunga, Western Ankole, Uganda. The field shows a euhedral crystal and smaller corroded forms of olivine, laths of melilite, and grains of perovskite in a groundmass of ore-sprinkled glass. × 15.

FIG. 2.—Katungite tuff. C. 3921. From the northern part of the crater rim of Katunga. The field shows corroded xenocrysts of biotite and augite derived from biotite-pyroxenite, a small xenolith of which occurs in the same section. × 15.

The Floor of the Arabian Sea.

By JOHN D. H. WISEMAN, Mineral Department, British Museum of Natural History, and R. B. SEYMOUR SEWELL, Leader of the "John Murray" Expedition to the Indian Ocean.

(PLATE XI.)

DURING the course of the John Murray Expedition some 22,000 miles of the floor of the Arabian Sea and the neighbouring areas of the Indian Ocean were mapped by means of the Echo-sounding apparatus. The region between India and Africa was crossed four times, namely:

(i) from Aden to Karachi,
(ii) from Bombay to Mombasa,
(iii) from Zanzibar to Colombo, and
(iv) from Colombo to Aden,

while more detailed surveys were carried out in the Gulf of Aden, the Gulf of Oman, and the region off Zanzibar.

The data thus acquired have been charted by Lieut.-Commander Farquharson, R.N., of the Hydrographic Department of the Royal Navy, who accompanied the expedition as Navigator and Surveyor;

and we now know that this region is traversed by several submarine mountain chains of varying length and height (Fig. 1), namely :

(*a*) Along the southern coast of Baluchistan and Persia is a line of interrupted ridges, that forms a barrier some 60 miles off the present coast-line, rising from the general level of the floor of the Gulf of Oman to within 732–914 metres of the surface, and separated from the mainland by basins that contain water of a depth of some 366–549 metres deeper than the barrier itself. This range is almost certainly a part of the Zagros System of Persia.

(*b*) Commencing from the neighbourhood of Cape Monze, near Karachi, a double ridge, with an enclosed deep gully, runs towards the south-west across the entrance to the Gulf of Oman. On the north-west side of the gully lies the "Murray" Ridge, which appears to be a continuation of the Khirthar range of Sind and rises to within 1,127–1,185 metres of the surface, while on the south-east side lies a second ridge that at one place has a depth of only 755 metres of water. The floor of the Gulf of Oman has an almost uniform depth of 3,383 metres, but in the gully the depth is 3,658 metres. As we trace these ridges and the enclosed gully to the south-west we find that the deep water of the gully seems to be continued for some distance, while the ridge on its south-east side also appears to be continued, for there is a series of shallow soundings that occur in line with it.

(*c*) These soundings, taken together, indicate the possibility that this "Murray" system may be connected with the great Carlsberg Ridge, which was so named by the late Dr. Johannes Schmidt,[1] who crossed the ridge in the *Dana* in about lat. 1° N., and who postulated its extension to join Socotra. As we trace this great mountain chain from the neighbourhood of Socotra, it is found to run at first towards the south-east and then after coming into close relationship with the submarine base on which the Chagos Archipelago is situated, bends first south and then west of south, and may be continued as far as the island of Roderigues, though the petrographical evidence does not support such a continuation. Throughout the greater part of its length from Socotra to the Chagos Archipelago this ridge appears to be double. Along the two crests numerous soundings between 2,291 and 3,059 metres have been made and the least water detected over them is 836 metres near the northern end, and 1,569 and 1,752 metres on the two ridges respectively in about lat. 1° 30′ N. where there is a depth of over 3,383 metres in the enclosed gully. On either side of this great ridge are deep areas in which the depth is about 5,121–5,303 metres. The Carlsberg Ridge seems to cease just to the south of Roderigues, but it is continued on as a low ridge, with some 3,650 metres of water over it, far to the south, and in all probability is connected

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[1] Schmidt, J., *Dana's Togt Omkring Jorden, 1928–1930*, Copenhagen, 1932, 255, fig. 198.

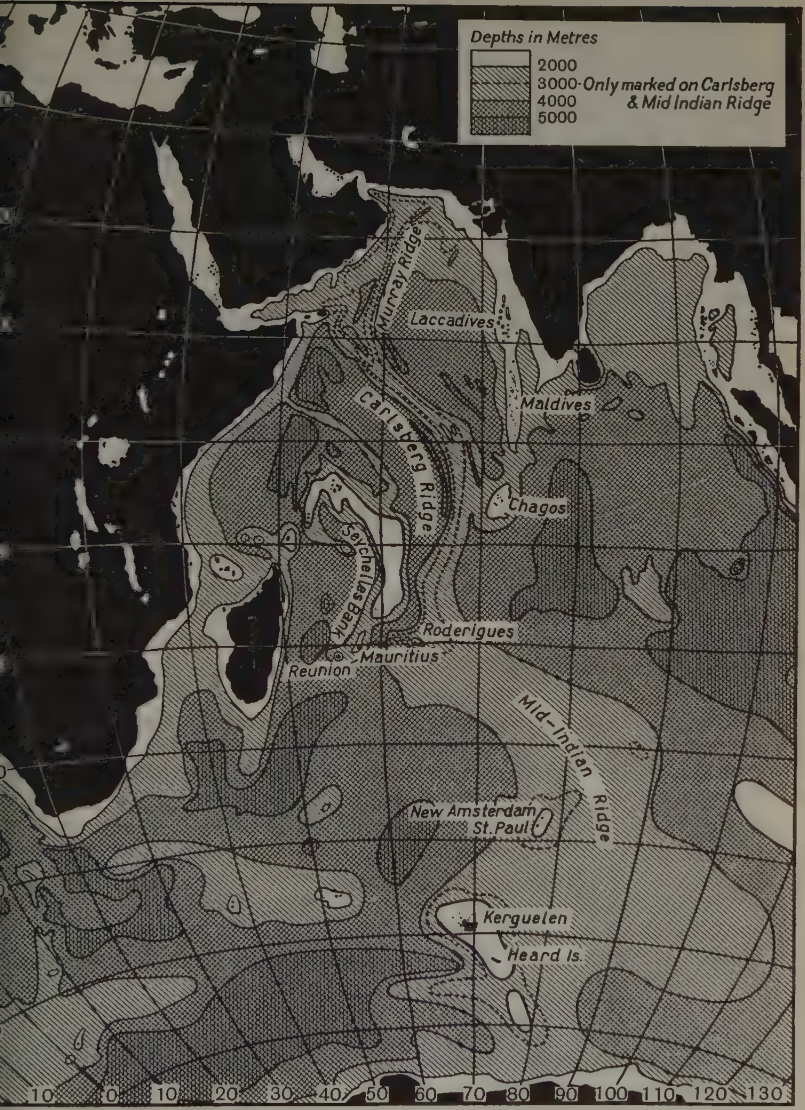

FIG. 1.—Bathymetric chart of the Indian Ocean.

with the Kerguelen Plateau,[1] from which rise the islands of St. Paul, New Amsterdam, Kerguelen, and Heard, and finally blends with the Antarctic continent.

(*d*) Commencing on the African coast in about lat. 4° N. and running a course concentric with the Carlsberg Ridge is another ridge of lesser height, but rising some 1,830 metres above the sea-floor.

(*e*) At its southern end this ridge may be continuous with the curved Seychelles–Mauritius Bank, on which lies near its northern end the Seychelles group, and at its southern end Mauritius. Between these are a series of banks, such as Saya da Malha, and Nazareth, that rise up to or very nearly to the surface.

(*f*) Finally between the Seychelles and Madagascar lies the base on which are situated Providence Island, Farquhar Island, and the Cosmoledo group, while in about lat. 16° S. we have the isolated island of Tromelin.

The great Carlsberg Ridge and its southern continuation thus form a Mid-Indian Ridge, running from north to south down the Indian Ocean, that reminds one of the similar Mid-Atlantic Ridge in the western ocean. This ridge divides the Indian Ocean into two, east and west, areas, while at the northern end there are several subsidiary basins, namely :—

(i) The north-east or Arabian Basin, bounded on its south-west by the Carlsberg Ridge and on the east by the coast of India and the Laccadive-Maldive Ridge, while at the northern end it is cut off by the " Murray " Ridge.

(ii) The basin of the Gulf of Oman.

(iii) The Somali Basin, lying to the south-west of the Carlsberg Ridge ; this latter basin, which is divided into two by the above-mentioned ridge (*d*) and the Seychelles–Mauritius Bank, has a maximum depth of 5,303 metres and each part is connected with the main western area of the Indian Ocean by a deep gully, having depths of some 4,570 metres. These gullies run respectively between Madagascar and the Seychelles, and the Seychelles and the Carlsberg Ridge.

In these three basins the nature of the sea-floor is quite different :—

(i) In the Gulf of Oman the basin is in its shallower regions floored with green mud, which in the neighbourhood of Cape Ras al Hadd is strongly impregnated with H_2S, while in the deeper areas grey clay occurs. This area is practically devoid of animal life between some 200 and 1,550 metres.[2]

(ii) Throughout the Somali Basin the sea-floor is composed of globigerina ooze, and supports, apparently, a normal animal population.

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[1] Wüst, G., " Anzeichen von Beziehungen zwischen Bodenstrom und Relief in der Tiefsee des Indischen Ozeans," *Die Naturwissenschaften*, 1934, 241.

[2] Sewell, R. B. Seymour, " The John Murray Expedition to the Arabian Sea," *Nature*, cxxxiii, 1934, 88.

(iii) The Arabian Basin in its deeper part is floored with red clay, with, at any rate in certain areas, a plentiful formation of manganese nodules. It is an interesting fact that this basin is also devoid of animal life in its deeper parts.[1]

THE CHARACTER OF THE COASTAL REGIONS.

Turning now to the character of the coastal regions, it has long been recognized that the west coast of India, in all probability, has been formed by extensive scarp faulting. Similarly Blanford [2] has put forward the view that there has been in the past a great fault running along the Makran and Baluchistan coasts, though Pilgrim [3] is of the opinion that the character of this coast is to be attributed to a widespread submergence, which " buried fathoms deep the steep mountain valleys, river systems and sea cliffs, which had been carved out during so many ages previously ".

The south-east coast of Arabia between long. 55° E. and Masira Island runs in a S.W.–N.E. direction, in a line that is an almost exact continuation of the African coast from Cape Guardafui southwards. Along this stretch of coast the geological formation consists of horizontally stratified sandstone alternating with layers of a harder material. This formation, which is clearly a sub-aqueous deposit, ends abruptly at the coast in cliffs that reach 400–600 feet in height. The continental shelf here is narrow, and at its seaward edge drops steeply and irregularly into deep water. As Farquharson [4] points out, " the slopes are extremely irregular, consisting of alternate slopes and valleys running out to seaward, in appearance similar to that of a mountain side." The same narrowness of the continental shelf and abrupt descent of the continental slope can be traced along the African coast as far as Point Malindi, just north of Mombasa. On the edge of the continental shelf opposite the Arabian coast lie the Kuria Muria Islands and Masira Island ; in the former the horizontal sandstone formation can be well seen in the eastern part, but at the western end of the main island, Jezirat Hallaniya, the strata are tilted upwards (Plate XI), and the extreme west end of this island and the adjoining Soda Island are composed of granite. The granite is intrusive into the sandstone formation, and its slopes can be traced down the continental slope to a depth of at least 1,370 metres. Clearly the stratified sandstone must have extended originally further to the south and south-east, and this, taken in conjunction with the general character of the coast, indicates that there has, in all probability, been an extensive scarp faulting along this and the adjacent African coast.

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[1] Sewell, R. B. Seymour, " The John Murray Expedition to the Arabian Sea," *Nature*, cxxxiv, 1934, 686.

[2] Medlicott, H. B., and Blanford, W. T., *A Manual of the Geology of India*, Calcutta, 1879, lxxi.

[3] Pilgrim, G. E., *Mem. Geol. Sur. India*, xxxiv, pt. 4, 1908, 60.

[4] Farquharson, W. I., *The John Murray Expedition, Scientific Reports*, i, 1936, No. 2, 49.

GEOLOGICAL EVIDENCE.

The Expedition was fortunate enough to obtain fragments of rock from the sea-bottom, both on the Carlsberg ridge and from the deep basin (4,800 metres) on its north-eastern side. All of these proved to be of basaltic type. Analyses by one of us (J. D. H. W.) have shown that these sub-marine basalts, as well as a third from the Andaman Sea Basin (depth, 2,286 metres), differ in a striking manner from the average composition of the Deccan Trap in India, for they contain considerably less total iron and in addition the Carlsberg Ridge rocks are poorer in potash. It thus seems clear that these basalts from the Indian Ocean cannot be regarded as a westward continuation of the Deccan Trap. Since geophysicists regard the earth as showing a gradual increase in iron from the periphery to the core, the question may be asked whether it is possible for continental basalts, which presumably have been thrust to the surface through a great thickness of sial, to originate at greater depths and consequently be richer in iron than those erupted on the ocean floor. Although at present it is impossible to give a complete answer to this question, it is interesting to note that Daly's average world plateau basalt (column 5 of the accompanying table) is richer in total iron than the rocks from the Indian Ocean.

TABLE OF ANALYSES OF BASALTIC ROCKS

	(1)		(2)		(3)		(4)		(5)	
SiO_2	51·12		46·55		50·65		50·61		48·80	
TiO_2	1·72		1·17		1·19		1·91		2·19	
Al_2O_3	14·81		18·13		17·07		13·58		13·98	
Fe_2O_3	2·35	9·14	5·89	10·59	2·16	8·17	3·19	13·11	3·59	13·37
FeO	6·79		4·70		6·01		9·92		9·78	
MnO	0·17		0·08		0·17		0·16		0·17	
MgO	7·56		3·82		7·74		5·46		6·70	
CaO	8·44		13·69		10·09		9·45		9·38	
Na_2O	3·93		2·34		3·15		2·60		2·59	
K_2O	0·13		0·57		0·36		0·72		0·69	
H_2O+	2·36		1·33		0·80		1·70		1·80	
H_2O-	0·54		1·03		0·31		0·43			
P_2O_5	0·14		0·92		0·18		0·39		0·33	
CO_2	*Nil*		*Nil*		*Nil*		*Nil*		—	
Incl.	—		0·04		—		—		—	
	100·06		100·33		99·98		100·12		100·00	

(1) Average of three unoxidized basalts from the Carlsberg Ridge. Analyst: J. D. H. Wiseman.

(2) Oxidized Variolitic Basalt from the North-East Basin, Indian Ocean. Analyst: J. D. H. Wiseman. As a certain amount of FeO has been oxidized by sea-water to Fe_2O_3, the total FeO + Fe_2O_3 is consequently slightly too high.

(3) Basalt from the Andaman Sea. Analyst: J. D. H. Wiseman.

(4) Average of eleven Deccan Trap analyses. *Bull. Geol. Soc. Amer.*, xxxiii, 1922, 774.

(5) Average World Plateau Basalt. *Igneous Rocks and the Depths of the Earth,* New York and London, 1933, 201.

A further very interesting difference between these sub-marine basalts and those of sub-aerial origin is to be found in the radium content. Dr. J. H. J. Poole has very kindly examined our specimens and has sent us the following data :—

	Radium-content in 10^{-12} gram per gram unit.
Basalt from the Andaman Sea	0·43
Station 133, Augite-basalt	0·46
,, ,, Variolitic basalt	0·49
,, ,, Hornblende-augite-dolerite	0·49
,, 166, Variolitic basalt	0·46
Average	0·466
Mean for Deccan basalts[1]	0·77
Basalt from Indian Ocean Islands[1] (Three specimens)	0·86
Average	0·815

Thus the sub-marine basalts contain approximately half the amount of radium as compared with land basalts. At present we are unable to put forward any explanation of this, though it may be possible that continental basalts acquire some of their radio-activity through contamination with richer layers during their upward passage.

At the southern end of the Carlsberg Ridge, the island of Roderigues is volcanic and so also are the islands of St. Paul, New Amsterdam, Kerguelen, and Heard, that rise from the southern part of the continuation of the ridge, namely the Kerguelen Plateau. The Seychelles–Mauritius Bank is also very largely volcanic, as is shown by the geological character of the islands Réunion and Mauritius; and, though the Seychelles group is largely composed of granite, a certain amount of basalt is also present. Between the Seychelles and Madagascar the bank on which Providence Island is situated is also now known to be volcanic.[2] The island of Socotra, like the Seychelles and the western part of the Kuria Muria Islands, is partly composed of granite.

We would here call attention to the apparent similarity which exists between the topography of the floor of the Arabian Sea and the region to the west of it that is characterized by the presence of the Great Rift Valley (Fig. 2). The Rift Valley commences at its northern end in the deep tectonic rift of the Red Sea, and its northern continuation the Jordan valley of Palestine is bounded on the west by the hills of Judaea. In the Arabian Sea we have, corresponding to this, the deep Murray Gorge, bounded on the north-west by the Murray Ridge and its probable northern continuation, the Khirthar Range of Sind. At its southern end the Red Sea opens into the Gulf of Aden which runs from west to east. At its eastern end the Gulf comes into close relations with the south-west extension of the Murray Gorge, thus forming, as it were, a connecting link between the Rift

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[1] Poole, J. H. J., *Phil. Mag.*, xlviii, 1924, 827.

[2] Wiseman, J. D. H., *Trans. Linn. Soc., Zool.*, Ser. 2, xix, 1936, 437.

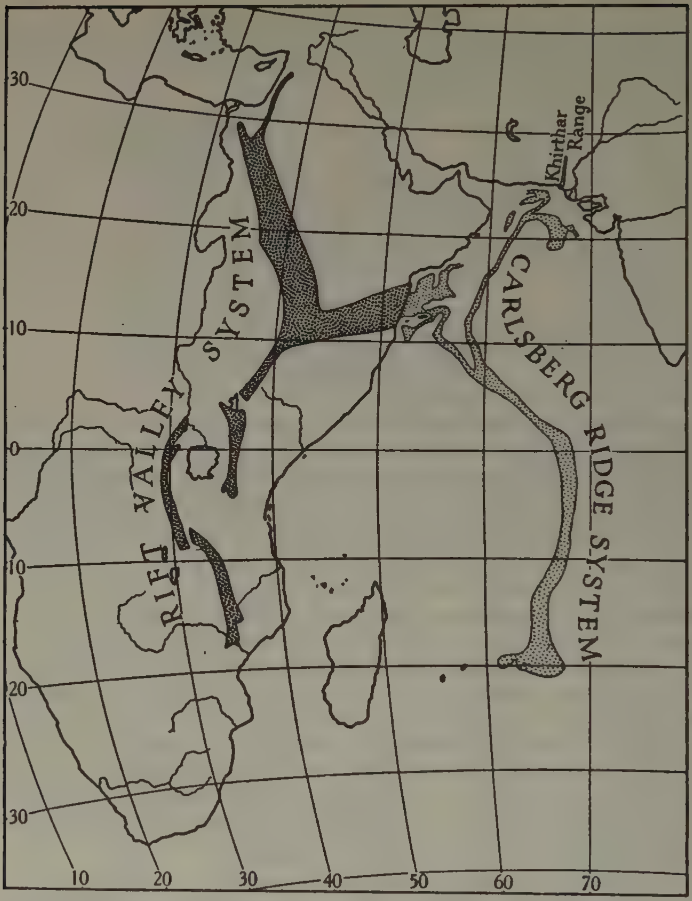

FIG. 2.—The Great Rift Valley and the Carlsberg Ridge System.

Valley of Africa and the deep gully that runs along the length of the northern part of the Carlsberg Ridge. The African Rift Valley, as a whole, sweeps in a wide curve towards the south-west, south, and then south-east, while the double Carlsberg Ridge runs a corresponding course towards the south-east, south, and then south-west. The two systems thus form an almost exact mirror reflection of each other on either side of the dividing line of the meridian of 50° E. (Fig. 2), and each appears to end in the neighbourhood of the parallel of 20° S. In our chart of the sea-floor the Carlsberg Ridge is shown as a continuous double fold, running approximately in the form of an arc. We know that the Rift Valley has in places been interrupted and the main line of its trend is shifted to east or west; but it must be borne in mind that as yet we are acquainted only with the broad lines of the Carlsberg Ridge and that there are stretches of several hundred miles in which we have only very few soundings. It is only the general trend of this great mountain chain that is known, and it is possible, indeed one might say probable, that there are interruptions along its length, as there are along the concentric ridge of the Seychelles–Mauritius Bank.

SEISMOLOGICAL EVIDENCE.

Heck[1] has recently published a paper in which he calls attention to the existence of a great earthquake belt, running round the whole earth. The major belt in the eastern hemisphere runs along the line of the Alpine–Himalayan mountain system; but secondary belts have been traced running to north and south. Of these secondary belts one is shown to extend southward along the Red Sea and then down the Rift Valley, and another can be traced across the Gulf of Oman and then down the middle of the Arabian Sea (Fig. 3), where we now know that the Carlsberg Ridge runs its course. A similar secondary belt can be traced down the length of the Mid-Atlantic Ridge. While providing us with an additional point of similarity between the Rift Valley and the Carlsberg Ridge, the presence of these earthquake belts indicates the lines along which the earth's crust is in a condition of instability, and this seems to be borne out by the variations in gravity that have been investigated by Meinesz and others.

GEODETIC OBSERVATIONS.

During our voyage through the Maldive Archipelago, we were fortunate enough to have on board Lieut.-Col. E. A. Glennie, R.E., D.S.O., of the Geodetic Branch of the Survey of India, and gravity observations were carried out at nine stations in this group of islands. As a result Glennie[2] reached the conclusion that throughout the length of the Laccadive Archipelago there is a positive anomaly, which he connects with a similar positive variation extending along the length of the Aravalli Mountains and the subsidiary Satpara Range in India. He suggests that the line of upwarp, which has formed this oldest range in India, is continued south and forms the base on which the coral islands of the Laccadives have been built. In the Maldive area the gravity anomaly was found to be negative, and Glennie interprets this as a result of a downwarp in the sima layer which he correlates with the downwarp present over the southern end of the Indian peninsula. If this be so, then it seems reasonable to conclude that there has been faulting between the Laccadive and Maldive Archipelagoes along the line of the Eight Degree Channel.

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[1] Heck, N. H., *The Geographical Review*, xxv, 1935, 125.

[2] Glennie, E. A., *The John Murray Expedition, Scientific Reports*, i, 1936, No. 4, 96.

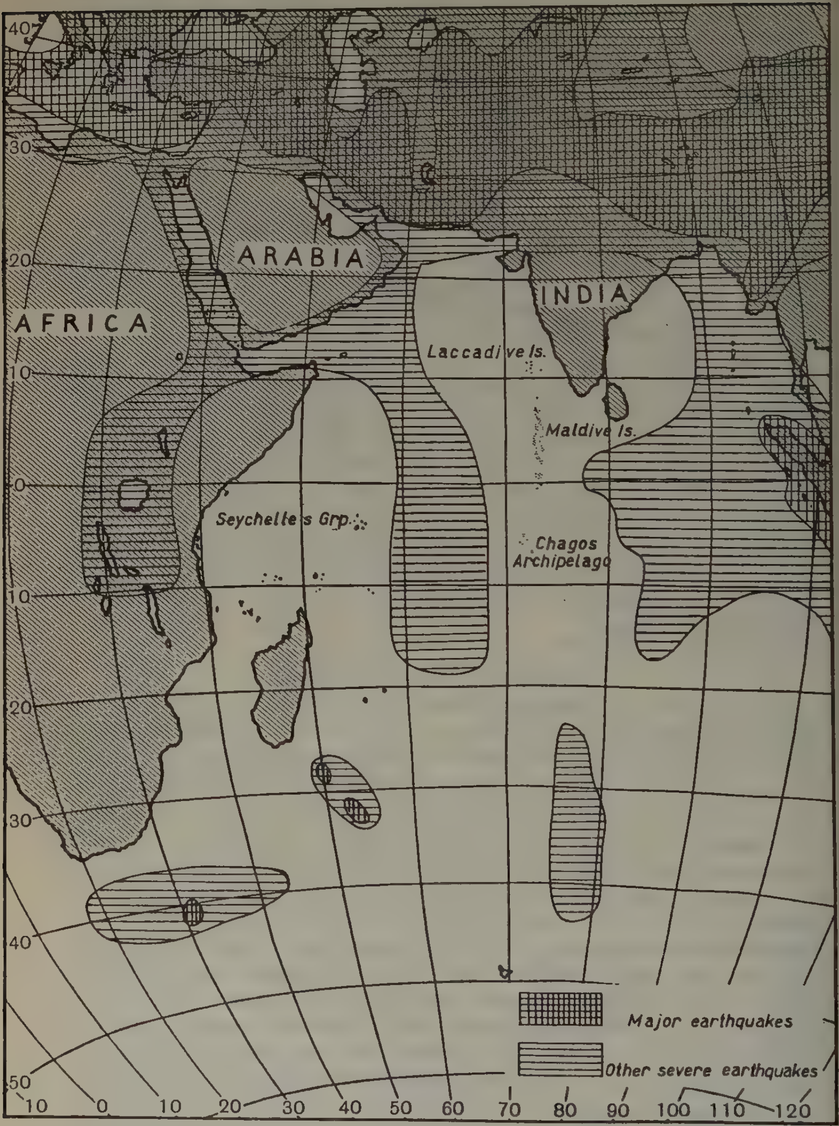

FIG. 3.—The Earthquake Zones of the Indian Ocean and neighouring areas (*after Heck*).

Meinesz[1] in his voyage across the Indian Ocean crossed the northern end of the Carlsberg Ridge and obtained evidence of a rise in the gravity anomaly in the region of the ridge, for his regional anomalies at the following stations were :—

Lat.	*Long.*	*Regional anomaly.*
10° 02′	55° 25′	− 9 milligal.
7° 57′	61° 54′	+ 1 ,,
7° 53′	65° 58′	− 27 ,,
7° 56′	68° 46′	− 31 ,,
8° 06′	72° 48′	− 61 ,,

Unfortunately the existence of the Ridge was not known at the time of his voyage, and Meinesz's stations just miss the major elevation ; but the variations in this area strongly remind one of the similar variation that has been shown to be present over the similar Mid-Atlantic Ridge. In a more recent paper Bullard[2] has shown that in East Africa gravity is on the average slightly deficient. A similar result was found by Meinesz for five stations in the Indian Ocean. Bullard also considers that " the isostatic anomalies are generally small over the plateau but that large negative values occur over most parts of the Rift Valleys, particularly over the western branch ". In addition the same author has shown that at some stations a little distant from the Rift, the anomalies are positive (+ 16 to + 21), and this would agree with the positive variation found by Meinesz to the east of the Carlsberg Ridge in lat. 7° 57′ N., long. 61° 54′ E. Along the African coast the gravity results seem to support the view that there is an off-shore rift of which the deep Pemba Channel is part. He concludes that " the distribution of matter under the Rifts can be accounted for if they have been formed by faulting and folding under horizontal compression, but not if they have been formed by tension ".

THE AGE OF THE CARLSBERG RIDGE SYSTEM.

We now come to the consideration of the age of the Carlsberg Ridge and its southern continuation, the Mid-Indian Ridge. We have already pointed out that the whole of the northern part of the Arabian Sea is surrounded by a series of faults. Blanford and other geologists have placed the age of the great fault down the west coast of India as Pliocene or Post-Pliocene. If, as we think, the Murray Ridge and its associated gorge is a continuation of the Khirthar Range of India, then its formation must have taken place in Eocene–Miocene times, and the fracture across it must have been subsequent to this. The faulting along the south-east coast of Arabia cuts across stratified sandstones and limestones that are almost certainly of the same age as the Makran Group of sandstones, namely Miocene or a little later, and hence this faulting must be subsequent to this, namely Pliocene or Post-Pliocene.

[1] Meinesz, F. A. V., *Gravity Expeditions at Sea*, Delft, 1934, ii, 89.

[2] Bullard, E. C., *Phil. Trans. Roy. Soc.*, Series **A**, ccxxxv, 1936, 445.

The topographical similarity between the Carlsberg Ridge and the great Rift Valley suggests the possibility that they are contemporaneous, and, if so, then the Carlsberg Ridge is Tertiary in age. It is significant to note that the islands at the southern end of the Mid-Indian Ridge are in all probability Tertiary, a fact which seems to have been definitely established for Kerguelen and is probable for the others, namely St. Paul, New Amsterdam, and Heard. Finally the volcanic agglomerate at the base of Providence Reef has been shown by one of us (J. D. H. W.) to be Eocene–Oligocene in age and probably contemporaneous with " the volcanic activity in the Ampasindara petrographical province, Madagascar ".

It is impossible to estimate the age of the basalts of the Carlsberg Ridge, but it seems highly probable that the floor of the north-west part of the Indian Ocean, as we know it to-day, assumed its present form as a result of compression in Tertiary times, probably contemporaneously with the upheaval of the Alpine-Himalayan mountain system and the arcs of the Malay Archipelago and the formation of the Rift Valley. Subsequently in Pliocene or Post-Pliocene times the area of land that once filled the triangle now bounded by the northern part of the East African coast and its continuation, the south-east coast of Arabia, the Baluchistan coast, and west coast of India, became separated off by a series of faults and was submerged to its present depth. There is little or no indication that any older continental mass or land isthmus such as the hypothetical continent of Gondwanaland or the isthmus of Lemuria, ever existed except in the granitic mass of the Seychelles and perhaps the corresponding granites of Socotra and the Kuria Muria Islands, and it is possible that these are all intrusives, similar to the intrusive granite masses that have been found in the Himalayas.[1]

EXPLANATION OF PLATE XI.

The northern coast of Jezirat Hallaniya, Kuria Muria Islands, showing upward tilting of the limestone strata.

REVIEWS.

Der Abbau der Gebirge. Band 1 : Der alpine Bauplan. By Ernst Kraus. Berlin ; Gebrüder Borntraeger, 1936. pp. xii + 352, with 57 figures in text, and map and four plates of sections in pocket of cover. Price R.M. 32.20 gebd.

THE title of this work expresses metaphorically the author's idea of the origin of mountain ranges. The word *Abbau* may mean the act of mining or the empty spaces left by mining. The suggestion is that the first step in the formation of a range is a kind

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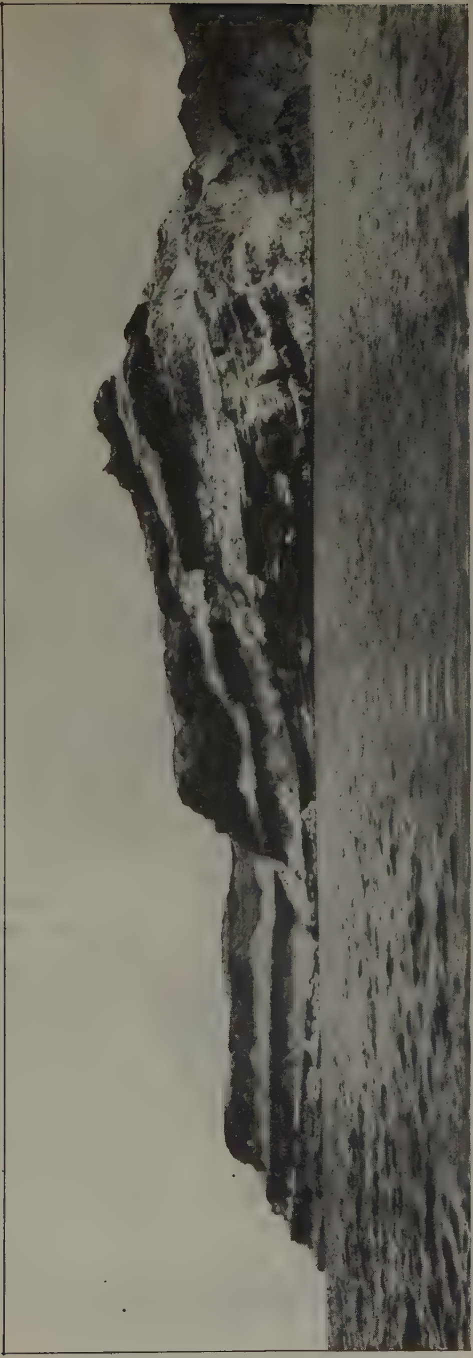
[1] Wadia, D. N., *Current Science*, iv, 1936, 691.



THE NORTHERN COAST OF JEZIRAT HALLANIYA, KURIA MURIA ISLANDS. NOTE THE UPWARD TILTING OF THE LIMESTONE STRATA.

[*Face p.* 230.

of undermining. This is the foundation of the hypothesis put forward by Ampferer in 1906, which in its essential features is adopted by Dr. Kraus. Beneath the site of a future mountain range there is a descending current in the subcrustal magma, and over this the crust bends down as a geosyncline. Lateral currents flowing towards the downflow drag together the sides of the geosyncline, causing compression and the formation of thrust-planes sloping down towards the central line. The process is one of underthrusting inwards rather than overthrusting outwards.

The present volume deals with the Alps. It is hardly necessary to say that the author belongs to the East Alpine school rather than the West Alpine. But in one respect he differs from both; he thinks that in origin the Alps are a double range. There were two descending currents along approximately parallel lines, one of which gave birth to the Northern Alps and the other to the Southern Alps. To prove his point he takes eight sections across the range and examines them in detail. The most westerly section is from the Isere valley to Turin, the most easterly passes through Graz; but he does not discuss them in order of position. He begins with the section from Allgäu to Lake Garda because this shows best the relation between the Western and Eastern Alps. From this middle line he proceeds first westward and then eastward. The sections are all drawn to the scale 1/300,000 without exaggeration of the vertical, and in each he indicates the position of his two descending streams. He also gives a structural map of the Alps on the scale 1/1,000,000, on which the lines of the sections are shown. Both map and sections are partly coloured and, though necessarily intricate, are remarkably clear. The whole work is very thorough and interesting but is much too complex to summarize here. All that we can do is to glance at the position of the two descending currents. One of them is beneath the Briançonnais zone in the west, beneath the inner limit of the Northern Limestone Alps in the east; the other lies at the Italian foot of the Alps in the west, and beneath the Steiner Alps in the east.

At the end of the volume the author gives an account of the orogenic cycle between two continents according to his theory, the cycle beginning with the birth of a descending current in the sima and ending with its decay and death. During the life of the current lighter material is dragged down into the sima and is faulted and folded in the process. When the current dies isostasy comes into play and this lighter mass rises, forming a mountain range. Since Dr. Kraus is a geologist it is rather surprising to find that he adopts the Hayford hypothesis and not the Airy theory. In his diagrams of the close of the cycle he makes the lower surface of the sial level and quite independent of the irregularities of its upper surface.

P. L.

AN ATTEMPT AT THE CORRELATION OF THE ANCIENT SCHISTOSE FORMATION OF PENINSULAR INDIA. By L. L. FERMOR. *Memoirs of the Geological Survey of India*, Vol. 70, Part 2, No. 1, pp. 53–217. 1936.

IN Part 1 of this memoir, reviewed in a recent number of this journal, Sir Lewis Fermor divided the Archaean rocks of India into regions and provinces for purposes of description. No. 1 of Part 2, which is the subject of the present review, describes three of these provinces—the Dharwar-Mysore-Nellore province, the Chanda-Bastar Province, and the Singhbhum-Orissa province.

The Dharwar-Mysore-Nellore Province.—This is the first province to be described, as it contains the so-called " classic ground in which Foote originally separated the Dharwar formation from the associated gneisses ". In other words its priority arises entirely from historical considerations.

Newbold's earliest view, expressed in 1844, that the granitic rocks had intruded into earlier schists and gneisses, was largely accurate and it is curious that over sixty years elapsed before this view became accepted. It is a fine illustration of how scientific advancement is so often held up by blind belief in a popular view.

R. B. Foote's first descriptive work on the South Indian rocks appeared in 1876, but it was not until 1886 that he proposed the term " Dharwar " for the schistose rocks which occur as wide bands in the " granitoid gneisses ", and later described eight such bands. He refers to the Dharwar system as " Lower Transition ", and, rejecting Newbold's views of the intrusive relation of the gneisses into the schists, concluded that the Dharwar rocks rested unconformably on the granite-gneisses.

J. Malcolm Maclaren, who worked in this part of India for a very short time at the beginning of this century, continued to believe in this stratigraphic unconformity between the Dharwars and granite-gneiss. Maclaren did no detailed mapping, yet he drew comparisons between these Dharwars and the rocks in Chota Nagpur, Rajputana, and even Behar and Shillong.

Then followed the work of the Mysore Geological Department, of which Foote himself was the founder. No comprehensive account of this part of India has appeared since Smeeth's outline in 1916. The Dharwars are divided into an upper (chloritic) and a lower (hornblendic) division without any break between the two, and the whole intruded by a succession of granites and basic igneous rocks, the Dharwars being recognized as the oldest rocks present. Smeeth, in 1926, concluded that the " lower division " is intrusive into the " upper ", a view which Jayaram later rejected. A calcareous and manganiferous division has also been recently recognized, and known as the " Sakarsanhalli series " which may be a still lower division. Of the intrusive granites the Peninsular gneiss is the most widespread

The various opinions as to whether the quartzites, ferruginous quartzites, limestones, and schists are of sedimentary origin or are due to replacement of igneous rocks are stated fairly enough by Sir Lewis, as also is the controversy concerning the sedimentary or crush origin of certain conglomerates. Notwithstanding that he refuses " to accept any conglomerate in the Archaean as truly sedimentary except on the most rigid proof ", an attitude which he so strongly assumes in Part I, it is good to read that he does acknowledge the recent views of Rama Rao and Pichamuthu that sedimentary conglomerates actually occur. His criticism of Iyengar's, Smeeth's, and Jayaram's inclusion of the intrusive Champion gneiss as part of the Dharwar system is justifiable.

Chanda-Bastar Province.—This extends north from the Godavari River and three-quarters lies in the Central Provinces. It is bounded on the east roughly by the Eastern Ghats and on the west by the Deccan Traps, Gondwanas, and Puranas. Little has been published concerning this tract during recent years, and the last memoir of any importance appeared in 1902—Sir Lewis refers to Smith's account of the Raipur and Sambalpur districts, dated 1899, as " fairly modern " ! Amongst other faulting Sir Lewis deduces evidence for a fault zone some 600 miles in length, which threw down the Chanda-Bastar Province several thousand feet relative to the adjacent Eastern Ghats Province.

During the last few years Geological Survey of India parties have been engaged in the Bhandara district of this province. Here the Sakoli series is regarded as younger than the Sausar series which crops out to the north. A survey of Bastar State, in the eastern part of this province, has recently been commenced. There a series of metamorphosed sediments have been intruded by granitic rocks; ferruginous quartzites form an important part of the series. Summarizing the features of the Chanda-Bastar province Sir Lewis notes that the phyllites, schistose rocks, and gneisses are more or less parallel to the general north–south trend of the rocks in the Dharwar-Mysore-Nellore province. The phyllite-schist suite has received different names in different areas: Sakoli series in Bhandara, Chilpi Ghat series in Balaghat and Drug, and Sonakhan series in Bilaspur, Raipur, and Sambalpur. All are compared with the Dharwars of South India. The chief rocks are slates, phyllites, mica-schists, chloritic, and hornblendic schists, quartzites, and hematite-quartz-schists. Calcareous rocks are entirely absent.

The province is very large, the schists are widely separated in the granite-gneiss. So little is known, apart from the Sakoli and Sausar series, that there is no justification for any correlation as yet between each area.

The Singhbhum-Orissa Province.—We come next to the area which has been my own hunting ground during the last fifteen years. It is a small province, but it will be interesting to see later the reason for the separation of the Ranchi and Bihar provinces which lie to the north, and which in actual fact form a very definite unit with Singhbhum geology. Economically it is the most important mineral tract in India.

Sir Lewis summarizes the early work of Haughton, Stoehr, Ball, Maclaren, and Fermor in Singhbhum and surrounding areas; of these Ball alone did any extensive mapping, but Fermor mapped about 20 square miles around some chromite deposits. The early views were more or less parallel to those expressed for South India, except that at no time was such a wholesale relation of schists to an igneous origin postulated. Ball's memoir (1881), the result of reconnaissance work of a most erudite type, was the most momentous, but to a modern reader it suffers from inhibitions attendant on the geological beliefs of those days—the same will certainly be said of our own work, perhaps, in the future!

An important omission is the work, in 1905–1908, of K. A. K. Hallowes, whose progress reports were available. He was the first to point out the intrusive nature of the granites into the schists, and there is much valuable information buried in Hallowes's reports.

A good account is given of the more modern detailed surveys which have covered approximately 10,000 square miles since 1920. The three principal workers, Jones, Dunn, and Krishnan, receive a good hearing, with also a mention of Dey's work; I should have liked to have seen some reference to the work of other colleagues, for example, to Hobson and Iyer, who have done some useful mapping in this area. This work has been recently described in several memoirs and others will appear shortly. But even so, I feel that our conclusions are unsatisfactory. Almost at the beginning Jones found that wonderful section along the Deo River, where the basal bed of the Iron-ore series rests on the vertical beds of an older metamorphic system—in no country have I seen exposed so clear a section of the unconformity between two Archaean systems. Almost from the beginning, therefore, we were aware that two systems of rocks were present: indeed, my own field work in India commenced from the actual site of this Deo River section. In Singhbhum and surrounding areas we have the following succession:

Iron-ore series.	7. Dalma lavas, with agglomerates and phyllites.
	6. Dhanjori quartzites (with occasional conglomerates)—impersistent.
	5. Phyllites with tuffs, lavas, limestones, conglomerates, quartzites.
	4. Banded hematite quartzite.
	3. Shales, phyllites, mica schists.
	2. Limestones—impersistent.
	1. Basal sandstone—conglomerate.

Older Metamorphic System.—The Older Metamorphic system does not cover a wide area, but wherever found its rocks are in every respect lithologically similar to the metamorphosed types of the younger Iron-ore series. Although no banded hematite-quartzites and iron-ores have as yet been found in the older group, the fact that pebbles of these ferruginous rocks occur in the basal conglomerate of the Iron-ore series indicates that such iron-ore rocks were present in the Older Metamorphic system. Lithologically the older system resembles the Dharwars of South India just as much as does the Iron-ore series.

The Iron-ore series should be regarded as a *system*, but it is the policy of the Geological Survey to retain the term *series* until correlations between widely separated areas have been effected. The unconformity between the Older Metamorphic system and the Iron-ore series represents a vast period of time, but in the Iron-ore series itself there are overlaps and erosion intervals permitting a grouping of the beds into stages. Going downwards in the system there was an erosion interval immediately preceding the Dalma lavas, a very considerable erosion interval preceded the Dhanjori quartzite and conglomerate, brief intervals occurred in the underlying stage of tuffs, etc., and finally, in South Singhbhum and Keonjhar, such a prolonged period of erosion preceded the banded hematite-quartzite that almost the whole of the underlying shales were removed and the Iron-ore beds occupy almost a basal position.

The outcrop of basal conglomerate immediately around the Deo River section is discussed as if it were a problem. There is no problem to those of us who have followed this bed along the strike—I personally have mapped it for over 30 miles, where it is found continuously between the granite and overlying shales and limestones. There is, however, a problem in regard to the adjacent Singhbhum granite. Most of this granite is definitely intrusive into the Iron-ore series, but I am of the opinion that some of the granite intrusive into the Older Metamorphic system is older than the Iron-ore series.

Continuing these surveys to the west, in Gangpur State, Dr. Krishnan has recently found a suite of calcareous rocks which he calls the Gangpur series, and which he believes to be older than the Iron-ore series, but younger than the Older Metamorphic system. Recognizing the several erosion-intervals within the Iron-ore series, some of which have been very prolonged, and having surveyed the country up to the border of Krishnan's area, it seems to me possible that the Gangpur series may represent a stage (not necessarily basal) of the Iron-ore series (or system) elsewhere removed. However, discussion of this may be preferably left until Krishnan's memoir appears and his evidence can be more fully appreciated. Fermor would correlate the Gangpur series with the Sausar series of the Central Provinces—still, 350 miles separate the two areas and correlation at this stage seems to be mere speculation.

Fermor remarks that in 1929 I discussed the possibility of correlating the Singhbhum rocks with the Dharwars of South India, following my predecessors. I no longer do so, however, for I regard such correlation as premature. Sir Lewis commences by accepting them as Dharwars, then sets out to prove his correlation.

At the end of each chapter the features of the province described are summarized and the lithological resemblances indicated on which a correlation with other areas may be suggested. These lithological grounds reach a maximum for the Singhbhum-Orissa province. They include such rocks as iron-ore deposits, hornblende-schists, aluminous rocks, manganiferous rocks, calcareous rocks, carbon-phyllites, ultrabasic rocks, and granophyres. Of the iron-ore deposits similar rocks must have occurred in the Older Metamorphic system, as also do hornblende and other schists, and ultrabasic rocks. Of the manganiferous rocks we have at least two horizons in the Iron-ore series, either of which could have given rise to gonditic types under suitable metamorphism, and there are also the manganese deposits in the Gangpur series. Calcareous rocks are present in the Iron-ore series, sometimes thick, but impersistent in this area—it is easy to visualize their swelling to the proportions known in the Gangpur series. Carbon-phyllites are present in both Iron-ore and Gangpur series; it is not correct to say they are less important in the Iron-ore series, as Sir Lewis believes. As to the intrusive granophyres, from pebbles in the Iron-ore series there was a pre-Iron-ore granophyre; another is intrusive into the Iron-ore series; and yet a third is an acid differentiate of the much later Newer Dolerites—microscopically identical with each other. These rocks provide no reliable evidence and I, personally, cannot accept any correlation on lithological grounds. To geologists not familiar with our Indian Archaean geology there is the possibility that resemblances marshalled in this way may appear to masquerade under the guise of logical premises. Time after time colleagues have discussed with me these lithological similarities to the Iron-ore series rocks, but in recent years I have believed it wiser to put a brake on this type of correlation, and await the accumulation of evidence which will form a more logical basis. The field of comparative stratigraphic succession should prove a valuable aid, however, and there are signs of its ultimate use in Fermor's account.

It appears that Fermor's correlation, so far as his account has gone, is approaching lines similar to those which have suggested themselves to his colleagues, but which they have hesitated as yet to pursue.

In this review I have found it a little difficult to sift the principal features from the mass of detail irrelevant to the object of the memoir. Furthermore, Sir Lewis has not always accurately recorded my less important views and I rather suspect the same on other minor points. I should like to have seen extracts taken from individual workers' own memoirs wherever possible rather than from General Reports; this particularly applies to the memoir of H. C. Jones, which was in Sir Lewis's hands some three or four years ago.

J. A. DUNN.

ORGANISCHE MORPHOLOGIE UND PALÄONTOLOGIE. By E. DACQUÉ, pp. viii + 476, with 27 text-figures. Berlin: Borntraeger, 1935. Price R.Mk. 32.20.

THIS is, as the author explains, no textbook of morphology or evolution, but is a metaphysical treatise in which an immense amount of information has been brought together and in which the advanced worker in palæontology will find an abundance of new ideas to recompense him for the extremely difficult reading.

It is impossible to review a work of this character or magnitude in the limits of space available, or even to give an adequate summary of all that the author has set out to do. The first half of the volume is devoted to "idealistische Morphologie"—the significance of the *Typus* or *Urform*, the conception of higher and lower types, ontogeny, genotypes, and phænotypes, etc.; and to the formal expressions of organic change—palæontological series, explosive-evolution, convergence, persistence, and the like. The second part deals equally exhaustively with certain aspects of theories of descent and phylogeny; and the third is a philosophical analysis of these problems, for "it is becoming clear that we have greatly over-estimated the universal applicability of the theory of evolution coined by zoological investigators and natural philosophers" and "to-day we are becoming aware that the *Deszendenzprincip* is not the all-embracing foundation for the illustration and explanation of organic forms".

While the arrangement is naturally not on systematic lines, a subject index of nearly twenty pages makes the search for particular matter comparatively easy.

O. M. B. B.

THE PLEISTOCENE FAUNA OF MAGDALENA BAY, LOWER CALIFORNIA. By E. K. JORDAN. Contributions from the Department of Geology of Stanford University, Vol. I, No. 4, pp. 107–173, pls. 17–19. Humphrey Milford, Oxford University Press, London, 1936. Price 9*s*.

THIS paper includes a revised list of the fauna, with short notes on about ninety of the species, and descriptions and figures of sixteen new mollusca. The fauna is considered to be tropical and "of near-shore character".

DIE ENTWICKLUNG DES AMERIKANISCHEN KORDILLERENSYSTEMS IN ZEIT UND RAUM. By HANS STILLE. *Sitzungsber. preuss. Akad. Wiss., Phys.-Math. Kl.*, xv, 134–155, 1936. (Sold separately, Gruyter and Co., Berlin, RM. 1.50.)

FOR many years Professor Stille has been studying critically and sifting the literature on the American Cordilleras, and he has made four journeys in them in Colombia, Venezuela, Canada, and the United States, in 1906, 1912, 1931, and 1933. The results of this work are being published as Heft 2 of Stille and Lotze's *Geotektonische Beiträge* (Borntraeger), of which the present essay is a summary. It is only 23 pages in length, but it provides a valuable supplement and extension of Philip B. King's brilliant *Outline of the Structural Geology of the United States*, written as Guidebook 28 for the sixteenth International Geological Congress, 1933.

The Alpine-type folding of the Cordilleras occurred in four main epochs :—

1. NEVADIAN (Late Cimmerian) (pre- and earliest-Cretaceous), with movement towards the west. To this epoch belong the western cordilleras from Alaska to Lower California, the Cascades, Sierra Nevada, etc. (excepting the Coast Ranges of California, Oregon, Washington).

2. ANDINE (Subhercynian) (Upper Cretaceous, pre-Senonian), with movement towards the east. The Andes from the north of Colombia to Cape Horn, and probably also the " South Antilles ".

3. LARAMIDE (pre- and early-Tertiary) with movement towards the east. The Rockies from Alaska to Arizona, swinging round to west of the Colorado Plateau (the Front Range and other mountains between the Colorado Plateau and the Great Plains are classed as only Germanotype mountains) ; their continuation through Mexico, Central America, and the Antillean Arc, and round to the Venezuelan-Colombian border via Curaçao. Round the Caribbean the movement was outwards, to north in the Greater Antilles, to east in the Lesser Antilles, to south in the islands parallel to the coast of Venezuela. Laramide folding also occurred in Southern Patagonia, and possibly in the " South Antilles ".

4. SUBANDINE (Upper Tertiary), with movement towards the east. This phase was of only subordinate importance and the folding was intermediate between Alpinotype and Germanotype. It produced the eastern sub-Andine chains from Venezuela to Northern Argentina.

In North America the western cordilleras and the Rockies arose from two virtually independent parallel geosynclines. The buckling of these at different periods is attributed to difference in the strength of the floor as indicated by the greater effusion of magma in the western geosyncline, both as lavas during subsidence and as plutonic intrusions during the buckling.

Kober's hypothesis that the Andes represent only the eastern half of a similar bilaterally symmetrical orogen, of which the western half has foundered beneath the Pacific, is rejected. The Andes correspond in their geosynclinal facies and magmatic history with the Nevadian ranges of North America, not with the Rockies. Only the date of folding and direction of movement are different. It is pointed out that the general strike of the South American cordilleras is by no means the same as that of the North American, but that they, in fact, make nearly a right angle; therefore movement so directed as to compress the one would not compress the other. Hence, perhaps, the difference in dates of folding in the two subcontinents.

Suess's conception of a "South Antillean Arc" analogous with the Antilles of Central America is defended and elaborated. In both the folding was outwards, and both lay between continental masses; the first between Antarctis and Gondwanaland, the second between Gondwanaland and Laurentia. Stille's generalized picture of the Antillean-Caribbean region is simpler than the picture of the same area presented in the recent large work by Schuchert, in which even the traditional continuity of the Greater and Lesser Antilles as a single arc is denied.

W. J. A.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY.

11*th March*, 1937.

"On a Universal Ore-Polishing Machine." By Dr. F. Coles Phillips.

A short account of the construction and use of a two-lap polishing machine available both for the usual methods of polishing by hand and for the automatic method developed at Harvard University. A description is given of the method of mounting specimens in synthetic material.

"On the Occurrence of Turquoise in Cornwall." By Mr. Arthur Russell.

A mineral assumed to be chrysocolla was collected from Bunny mine, Stenalees, St. Austell, many years ago when the mine was working. The best specimens came from the 80-fathom level in the main lode. In 1931 Mr. Herbert Thomas, of Truro, collected from the mine dump some of the same material which proved on chemical analysis to be turquoise. Another locality for turquoise has now been discovered at Castle an Dinas wolfram mine, St. Columb Major, Cornwall. It occurs in veins in tourmalinized slate with wolfram, scorodite, and wavellite.

"The Deuteric Mineral Sequence in the Enoggera Granite, Queensland." By Miss Marjorie J. Whitehouse (communicated by the President).

The minerals found in veins and vughs in this granite near Brisbane are described. The period of main magmatic consolidation was followed by pegmatite formation and the initiation of cavities in the rock. While the rock was still hot the deuteric period occurred beginning with the kaolinization of the felspars and the chloritization of the ferro-magnesian minerals. Then followed the deposition of chlorite and epidote, the pneumatolytic minerals, some calcite, the zeolites (prehnite, laumontite, gismondite), and, finally, many vughs were completely filled with calcite.

"On Iron-Rhodonite, Pyroxmangite, and their Relations to Rhodonite." By Mr. M. Perutz (communicated by Professor C. E. Tilley).

Determinations of the unit-cell of iron-rhodonite and approximate measurement of the dimensions of pyroxmangite have been made. The similarity of the structures of iron-rhodonite and pyroxmangite is established. By comparison with Gossner's description of rhodonite the conclusion is arrived at that the structure of the former minerals is different from that of rhodonite. After a determination of the density, volume, and mass of the cell of iron-rhodonite, possibilities of relations with enstatite are suggested.

CORRESPONDENCE.

BALLARD DOWN FAULT.

Sir,—It is disappointing to learn from Mr. Arkell's paper in the February number that there is no evidence to support his assertion that there is younger *mucronata* chalk below the fault than the *mucronata* chalk above it. (He has no "new evidence", and there can hardly be any old evidence in support of an assertion first made in 1936.) What becomes of the argument he based on this assertion?

When I wrote "any dip visible in Studland Bay" I did not say, but I meant (and, as I should have thought, obviously) visible *in the chalk*, the only formation under discussion, and the only formation to which my comment that the face on which it showed dip was in truth an east and west face and the dip shown wholly westerly, could apply. I think Mr. Arkell's criticism of my words must have been written with his tongue in his cheek. To my *intention*, whether obvious or cryptic, his criticism is mainly irrelevant.

Mr. Arkell's method of blunting my point about the perfect preservation of very delicate fossils close up to the fault is not very convincing. No doubt chalk may be bent once without any damage to delicate fossils; my experience of chalk suggests that it could never be bent to *and* fro even once without damage to delicate fossils; and Mr. Arkell's hypothesis seems to contemplate more than one bending to and fro.

I agree that he is unable to understand my hypothesis, and by stating this he scores off me. But as I did not attempt or profess to put forward a hypothesis, I think the score is rather a weak one and perhaps hardly worthy of being registered against me by a member of my old college.

However, Mr. Arkell's attitude has had one good result (if good is the right word). It has pricked me into attempting to frame a hypothesis myself, and this I hope will not be obscured even if I use "which" five times in seven lines.

R. M. Brydone.

Ivy Farm House,
Mundesley, Norfolk.
16th March, 1937.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXIV.

No. VI.—JUNE, 1937.

ORIGINAL ARTICLES.

On Silurian and Cambrian Rocks encountered in a Deep Boring at Walsall, South Staffordshire.

By A. J. Butler.

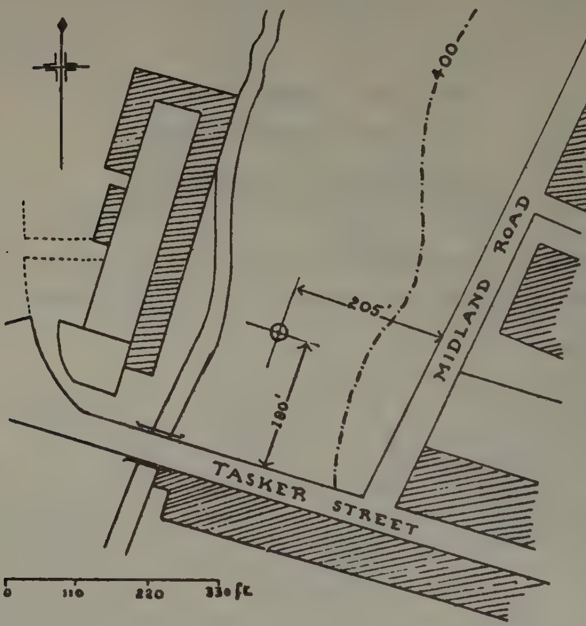
THIS paper records the succession which was encountered in a boring made during 1935 at Walsall, South Staffordshire. The site of the boring is precisely indicated in Text-fig. 1.

Wenlock Limestone was met with below the Drift at a depth of 42 feet. A further 5 feet were chiselled, rotary boring then began, and a complete set of cores were drawn from 47 feet below ground level to 1,285 feet, when the boring ended in Cambrian Quartzite.

Through the courtesy of the engineers, Messrs. Le Grand, Sutcliff, and Gell, Ltd., and of the Directors of the Walsall Co-operative Society, I was able to visit the site at frequent intervals from March to September. A detailed record of the succession was drawn up, and an attempt was made to collect and accurately to localize every identifiable fossil; except for a few barren sections, totalling some 30 feet in length, the whole of the core was broken and examined inch by inch. Both Salopian and Valentian strata proved extraordinarily fossiliferous, and their shelly fauna will be described in a subsequent paper.

The lithological succession is given below in summary, since complete reproduction of the boring record would involve monotonous repetition. Mr. A. Smale, the foreman in charge of the boring, gave valuable assistance by constantly checking the levels whence cores came, and by taking care that no inversion occurred when they were laid out; as a result the measurements here recorded are accurate within a small margin of error. The strata encountered in the first 800 feet of boring were completely horizontal; below this level a slight dip was observed, gradually increasing with depth to about 6° at the Cambrian-Silurian junction (1,253 feet). The observed thicknesses of successive divisions may therefore be regarded as true thicknesses, without error in the first 800 feet, and with negligible error below this level.

I am much indebted to my wife for assistance throughout the field work and in the preparation of this account.



TEXT-FIG. 1.—Sketch-map of a part of Walsall, South Staffordshire, showing the site of the boring.

GROUND-LEVEL APPROXIMATELY 388 FT. O.D.

		feet.	feet.
(A)	Soil	3	3
(B)	Sand and Gravel	39	42
(C)	Limestone (chiselled)	5	47

Rotary Boring began.

(D) Regularly bedded, dark grey to grey-brown, fine to medium-grained limestone, in beds from 2 in. to 5 in. thick, with thin partings of grey shale. The limestone is relatively unfossiliferous, containing only occasional brachiopods and crinoid fragments. The top 6 ft. of the core contained nearly vertical veins, ¼ in. to 2 inches in thickness, of fine-grained grey-green dolomitic limestone, weathering rapidly brown; small fragments of the normal grey limestone occurred in the dolomitic limestone. Below the dolomitic veins, and occupying a continuation of one

		feet.	feet.
	of the fissures which they filled, was a vertical vein of white calcite, about ¼ in. in width, which extended downwards through a further 14 ft. of core	24	71
(E)	Large irregular nodules and unevenly bedded bands of fine-grained, grey, argillaceous limestone, coarsened in parts by fragments of organisms, set in irregular partings of grey shale, thicker than the partings in (D). Flecks of pyrite occur in the limestones	8	79
(F)	Grey and grey-brown mudstones with many nodules and thin irregular bands of grey, fossiliferous, impure limestone, mainly fine-grained but coarsened in places by fragments of fossils. Flecks and cubes of pyrite are common in the limestone nodules. There is a definite reduction in the total lime content in contrast with the division above	9	88
(G)	Grey and grey-green mudstones, with fairly frequent bands of small nodules. Softer and less calcareous than the division above. The bands of nodules become scantier towards the base of the division. Highly fossiliferous	115	203
H)	Dark grey and grey-brown mudstones with very few calcareous nodules, but containing occasional thin bands of limestone, ¼ in. to 1 in. thick, which are composed almost wholly of fossils, mainly clusters of brachiopods and small corals. The mudstones are softer than in the division above, and there is continued downward decrease in total content of calcareous matter. A few bands of greenish-grey mudstone occur in the bottom 50 ft. of the division	181	384
(I)	Soft mudstones with occasional bands of small nodules and thin beds of shelly limestone. Very like the division above but of alternating grey-brown and grey-green tints, the grey-brown predominating. Many brachiopods and small corals	235	619
(J)	Fossiliferous mudstones, as division (I), but with the grey-green bands predominating over the grey-brown	30	649
(K)	Fossiliferous grey-green mudstones, harder than those in the division above, containing bands of grey, argillaceous fine-grained limestone; the frequency of occurrence of these increases, and they become individually thicker, towards the base of the division. Fewer fossils than in the softer mudstones above	113	762
(L)	Frequent beds, 6 in. to 9 in. in thickness, of mainly fine-grained grey limestone, set in grey shales containing many large calcareous nodules and lenticles. The limestones occupy the bulk of the division and are most closely set in the lowest 15 ft. Few fossils	33½	795½
(M)	Grey mudstones and shales with only occasional nodules and thin bands of limestone; calcareous beds are particularly scanty in the lower part of the division	74½	870
(N)	Alternating purple and grey-green shales. The grey-green tint predominates. There are no calcareous nodules, but occasional beds of limestone occur, varying from ⅛ in. to 2½ in. in thickness, and largely composed of brachiopods, and also a few thin beds (¼ in. to ½ in. thick) of fine yellowish-brown siltstone. The division is highly fossiliferous throughout	47	917
(O)	Mainly soft purple and maroon shales, together with occasional bands of grey-green shale; bands of grey limestone, up to 5 in. in thickness; a few thin beds of		

		feet.	feet.
	fine yellowish-brown silt; and beds of hard fine-grained grey siltstone with a calcareous cement, containing white mica, and from ½ in. to 3 inches in thickness. Many of the last show current bedding; their frequency of occurrence is greatest in the lower part of the division, as is also that of the limestone bands. The division yields a rich shelly fauna, particularly large brachiopods . .	193	1,110
(P)	Fine-grained, hard brownish-purple sandstone with a calcareous cement, uniform throughout except for a 9 in. parting of purple shale 2 ft. 6 in. from the top, and a similar 1 in. band 15 inches below the base of this. The top 12 inches very irregularly bedded, containing deep current-swept pockets defined by thin partings of purple shale. The bottom 8 ft. 6 in. of the cores contained thin vertical veins of calcite. Unfossiliferous except for a few unidentifiable brachiopod fragments	16	1,126
(Q)	Alternating purple and maroon shales and bands of hard grey calcareous siltstone, with very few fossils. The siltstones occur mainly in beds up to 6 in. thick, but one thicker bed, 1 ft. 9 in., occurs 4 ft. 3 in. from the top of the division	23	1,149
(R)	Fossiliferous grey and purple shales, the grey predominant, together with a few bands of grey micaceous siltstone mostly 1 or 2 in. thick, and occasional thin beds of shelly limestone	76	1,225
(S)	Fossiliferous dark grey shales with thin calcareous and silty beds mostly about 1 in. but up to 2½ in. in thickness; the shales are much in excess of the siltstones. There is little variation throughout. At 1,235 ft. was noted a lenticle, ½ in. in greatest thickness, of coarse quartz sand cemented by calcite, and several similar lenticles occurred in the cores from the lowest 18 in. of the division. 3 in. from the bottom of the division were found two small pebbles of white quartzite a little over 1 in. in diameter. At the actual base occurred a lenticular bed, 1 in. in greatest thickness, of coarse quartz sand with a calcareous cement, resting on the hollowed surface of the quartzite below . . .	28	1,253
(T)	Hard fine-grained white quartzite with a few shale partings. The top of the quartzite as seen in the cores was weathered, irregularly hollowed, and smoothed.[1] There was no evidence of great angular discordance between the beds of divisions (S) and (T). The dip near the base of (S) was about 6°. The dip of the quartzite, measured along the shale partings, varied from 8° to 15°; the quartzite itself fractured along smooth planes dipping at angles up to 30°, indicating false bedding. An intensive search for fossils in this division gave no results	32	1,285

Fuller details of the succession in division (T) are set out below:—

BASE OF SILURIAN, 1,253 FEET.

	ft.	in.	ft.	in.
White fine-grained quartzite	1	5		
Green shale		¼		
White fine-grained quartzite	1	9		
Dark grey shale		1		

---

[1] The piece of core showing this surface is in the Geological Museum of the University of Birmingham.

	ft.	in.	ft.	in.
White fine-grained quartzite		3½		
Quartzite with thin irregular partings of green shale		1		
White fine-grained quartzite	1	0		
Fine-grained grey sandstone with many thin partings of black shale		7½		
Black shale		1		
White fine-grained quartzite		4½		
Greenish sandy shale with much white mica		1½		
White fine-grained quartzite	1	2	1,260	0
Black shale with white mica		1¼		
Grey micaceous sandstone		1½		
White fine-grained quartzite	2	7		
Green shale		¼		
White coarse-grained quartzite	1	11		
Green sandy shale		½		
White coarse-grained quartzite	1	3½	1,266	1
White fine-grained quartzite	2	4½		
Green shale		¼		
Greyish-white coarse-grained quartzite	2	1		
Green shale		½		
White fine-grained quartzite	2	1		
Green shale		¼		
Grey fine-grained quartzite	3	4½	1,276	1
Green sandy shale		¾		
Greyish-white fairly fine-grained quartzite	4	1¼		
Quartzite with thin streaks of green shale		¾		
White fine-grained quartzite		2½		
Green shale		⅛		
White fine-grained quartzite		3		
Green shale		⅛		
White fine-grained quartzite		5		
Green shale		⅛		
White fine-grained quartzite		2½		
Greyish fairly coarse-grained quartzite	2	2		
Green shale		½		
Greyish fairly coarse-grained quartzite		7		
Green shale		½		
Greyish fairly coarse-grained quartzite		9	1,285	0

The terms "grey-brown" and "grey-green" in the descriptions of divisions (D)–(O) do not connote vivid colorations, but minor variations in the tint of the essentially grey mudstones, subdued but sufficiently distinct to provide one of the bases of lithological subdivision.

In the mudstones and shales of divisions (I)–(S), "fucoid" markings of the type abundant in the Rubery Shale Series of Rubery are common. They occur both parallel to the bedding and cutting across it as vermiform tubular markings up to ¼ inch in diameter, often flattened and irregularly intersecting.

CORRELATION.

(1) *Graptolites.*—Miss Elles has kindly identified the graptolites which were obtained from the cores; these are listed below:—

Division.		*Depth.* ft.
(A) to (G)	None.	
(H)	*Monograptus priodon* (typical)	205, 358, 369
(I)	,, ,, ,,	486
(J) to (L)	None.	
(M)	*M. priodon* *Cyrtograptus murchisoni*	831½
(N)	None	
(O)	? *M. vomerinus*	931
	M. vomerinus or *M. vomerinus* var. *crenulatus*	1,022
	M. vomerinus var. *gracilis*	1,070
(P)	None.	
(Q)	*M. priodon*	1,133
(R)	,, ,,	1,169, 1,181, 1,191
	,, ,, (early var.)	1,202, 1,205
	M. marri (2 specimens)	1,206
(S)	*M. discus*	1,226
	M. priodon	1,229
	,, ,, (early var.)	1,229
	M. marri	1,247

This graptolite fauna, though scanty, throws some light on the zonal division of the bore-hole succession. The occurrence of *Cyrtograptus murchisoni* shows that the base of the Salopian is at least as low as 36 feet below the base of the limestone division (L). A poorly preserved specimen from 1,022 feet may be either *Monograptus vomerinus* or its variety *crenulatus*, and Miss Elles states that *M. vomerinus* var. *gracilis*, which is fairly common at the base of the Wenlock, is known also to occur in the *crenulatus* zone ; it is therefore not possible accurately to define the Salopian-Valentian junction, but these varieties of *M. vomerinus* suggest that it should be placed somewhere between the 870 and 1,100 ft. levels.

Miss Elles notes that the graptolites from the divisions (Q) and (R) are " suggestive of the Upper Valentian . . . the *priodon* forms are mainly the types that I regard as an early mutation of the typical species, associated with the late mutation of *M. marri* and a few real *priodons* ", and that those from division (S), *M. discus*, *M. marri*, and early forms of *M. priodon*, suggest a horizon at least as low as the *griestoniensis* zone. It is possible that the *crispus* zone is also represented.

The graptolites give no conclusive evidence concerning the presence of zones higher than that of *M. crenulatus*. The occurrence of *M. priodon* indicates that division (H) is at least as low as the *linnarssoni* zone.

(2) *Brachiopods.*—The shelly fauna of the Silurian rocks is not here discussed in detail, but the occurrence of numerous specimens of *Stricklandia lirata* (J. de C. Sowerby) is worthy of mention. Specimens which can be attributed to *S. lirata forma typica* are particularly abundant. The vertical distribution of these and other forms of the species, and of specimens of *Pentamerus oblongus*, is indicated below :—

		STRICKLANDIA LIRATA					PENTAMERUS OBLONGUS
		Forma Typica	Near Forma Typica	Forma α	Near Forma α	Other Forms	
O	950						
			×				
	975	×					
		×					
		×					
	1,000	×					
		×					
		×				×	×
		×	×		×		×
		×					?
	1,025	×	×		×	×	
		×					
		×					
		×					
		×					
	1,050	×				?	
		×					
		×				?	
			×				
	1,075	×					
		×					
		×					
		×			×		
	1,100				×		
					×		
		×					
P			×				
		×					
	1,125						
Q		×					
	1,150						
R							
			×	×			
						×	
	1,175						
				×			
	1,200						
						×	
				×			
	1,225			×			

The cores were divided into successive lengths of 5 feet; the shelly fossils from each of these lengths were parcelled together. A cross between 1,050 and 1055 ft. levels thus indicates that at least one specimen of the form in question was found somewhere between these levels. *S. lirata forma typica* was particularly common in all the divisions from 990 to 1,060 feet. A particularly large specimen was found in the 980 to 985 ft. division. Where the identification is doubtful ? is used instead of a cross.

. . . . .

Stricklandia lirata has recently been described in some detail by J. K. S. St. Joseph,[1] who advances a good reason for including those Silurian beds in which *S. lirata forma typica* occurs in abundance in the Valentian Series. On this basis the upper limit of the Llandovery beds can be placed at least as high as the 990 ft. level and perhaps as high as the 970 ft. level.

(3) *Lithology*. Some correlation of the bore-hole succession with established subdivisions of the Silurian rocks of the Birmingham area can be made on lithological grounds.[2]

(*a*) The upper 30 feet of the Lower Wenlock Limestone of the Walsall and Dudley Silurian outcrops consists of evenly bedded grey limestone divided by very thin regular shale partings into beds from 3 to 12 inches in thickness; this division can be conveniently called the "Quarried Beds". It is underlain by about 10 feet of rubbly nodular limestones with thick irregular shale partings (the "Basement Beds") which are transitional to the Wenlock Shales beneath. The limestone (D) of the bore-hole is lithologically identical with the Quarried Beds of the outcrops, and the beds of division (E) with the Basement Beds.

(*b*) The monotonous series of calcareous mudstones and shales of divisions (F) to (K), 683 feet in thickness and lithologically divisible only on the basis of slight variation in colour and on the frequency of occurrence of calcareous nodules and limestone bands, can without hesitation be ascribed to the Wenlock Shale. The observed thickness corresponds fairly well with previous estimates based on width of outcrop.[3]

(*c*) There can be no doubt that the limestone division (L) is the representative at the bore-hole site of the Barr Limestone which outcrops to the east of Walsall, and which it resembles in lithology and in thickness.

[1] "A Critical Examination of *Stricklandia* (= *Stricklandinia*) *lirata* (J. de C. Sowerby), 1839, *forma typica*," Geol. Mag., 1935, LXXII, 401–424.

[2] An account of geo-electrical measurements in the boring is given by S. H. Shaw, *Mining Mag.*, 1937, lvi, pp. 205–206, who suggests that an increase in resistivities observed at and below 920 ft. may mark the Wenlock-Llandovery junction.

[3] See, for example, the *Lichfield Memoir* (Explanation of Sheet 154) *of the Geological Survey*, 9.

(*d*) There is no unconformity to mark the Llandovery-Wenlock junction; the lithological succession appears unbroken.

The beds below the Barr Limestone cannot be satisfactorily correlated on lithological grounds with the Llandovery outcrops of the Birmingham district. There is, in fact, considerable contrast, particularly in the lower part of the succession, with the beds below the "Woolhope" Limestone at Rubery.[1] Division (P), however, 16 feet of fine-grained, purple-brown, calcareous sandstone, is very similar, allowing for its unweathered condition, to the sandstone of Upper Llandovery age which is exposed in a small faulted inlier at Great Barr, 2½ miles south-east of the bore-hole site.

(*e*) The hard unfossiliferous white quartzite (T), which forms the lowest beds reached by the boring, strongly resembles the Cambrian Quartzite of the Lickeys and other Midland outcrops; the base of division (S) rests on the top of (T) with small but distinct angular discordance, and pebbles of the quartzite occur in the lowest beds of (S). There seems no doubt that this quartzite is of Cambrian age. The green shale partings which occur in the quartzite are superficially similar to the Silurian bentonitic clays which are described in the last section of this paper, but examination of their physical properties and in thin section shows that they are normal detrital sediments and are not bentonitic (see p. 257).

The presence of Cambrian rocks beneath Llandovery sediments at Walsall which was suggested by Wills[2] is thus confirmed by the bore-hole record.

. . . . .

Taking into consideration both lithological and faunal evidence the succession can therefore be grouped as shown in Text-fig. 2. It seems reasonable to place the Llandovery-Wenlock junction at the 970 ft. level, 53 feet from the top of the purple shale division (O), thus including all the beds in which *Stricklandia lirata forma typica* occurs in the Llandovery. This position does not correspond with the level of transition from purple to grey sediments; lithological type, however, cannot be regarded as an accurate guide to the junction; the Purple Wenlock Beds of Shropshire described by Whittard may be quoted as an example.[3]

SEDIMENTATION OF THE SILURIAN ROCKS.

(*a*) *Llandovery.*—As noted above, the basal beds of the Silurian rocks contrast strongly with those at Rubery, 15 miles to the south, where about 30 feet of coarse sandstones containing abundant pebbles of Cambrian Quartzite (The Lower Sandstone Group, Wills,

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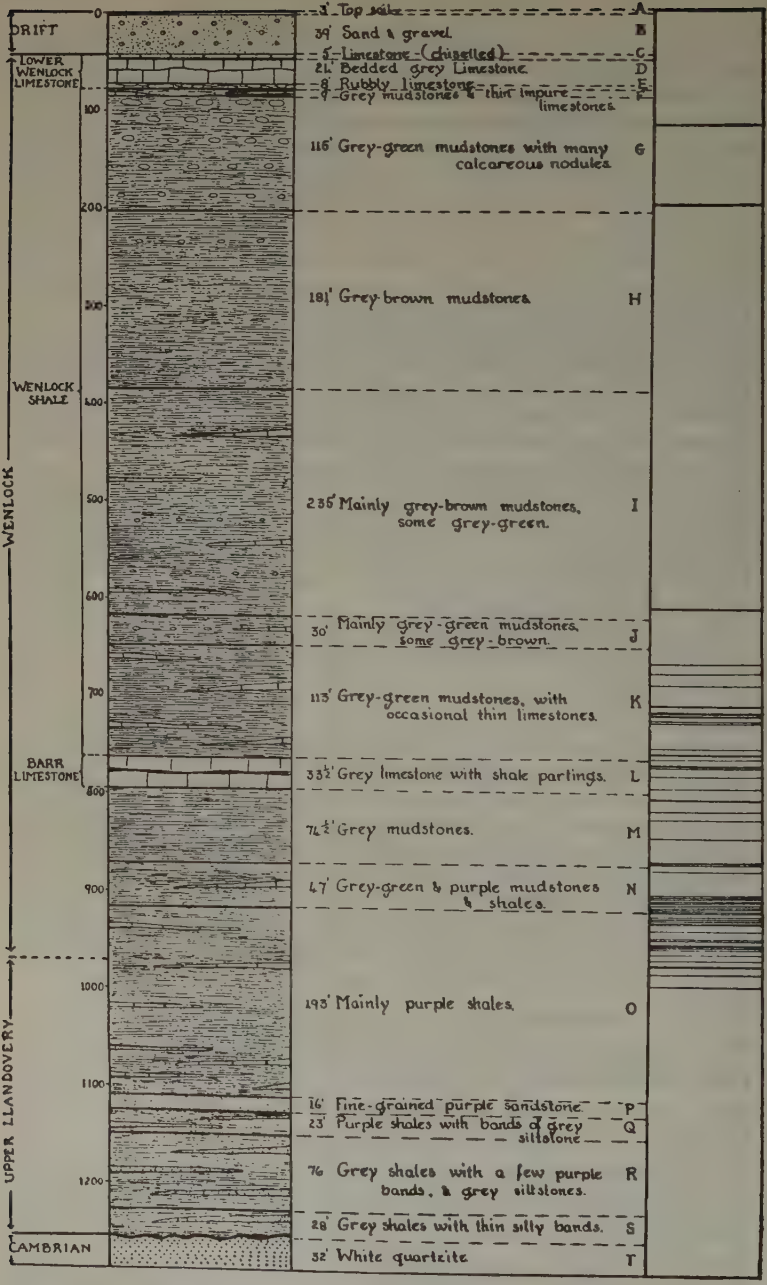
[1] L. J. Wills and others, "New Exposures in the Rubery-Longbridge-Rednal District, South of Birmingham. B: The Upper Llandovery Series of Rubery," *Proc. B'ham. Nat. Hist. and Phil. Soc.*, xv, part iii, 1925, 67–83.

[2] L. J. Wills, "An Outline of the Palaeogeography of the Birmingham Country," *Proc. Geol. Assoc.*, xlvi, 1935, pt. ii, 217.

[3] "The Stratigraphy of the Valentian Rocks of Shropshire. The Longmynd-Shelve and Breidden Outcrops," *Quart. Journ. Geol. Soc.*, 1932, lxxxviii, 869.


DRIFT
LOWER WENLOCK LIMESTONE
WENLOCK SHALE
WENLOCK
BARR LIMESTONE
UPPER LLANDOVERY
CAMBRIAN
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
3' Top soil A
39' Sand & gravel B
5' Limestone (chiselled) C
24' Bedded grey Limestone D
8' Rubbly limestone E
9' Grey mudstones & thin impure limestones F
116' Grey-green mudstones with many calcareous nodules G
181' Grey-brown mudstones H
235' Mainly grey-brown mudstones, some grey-green I
30' Mainly grey-green mudstones, some grey-brown J
113' Grey-green mudstones, with occasional thin limestones K
33½' Grey limestone with shale partings L
74½' Grey mudstones M
47' Grey-green & purple mudstones & shales N
193' Mainly purple shales O
16' Fine-grained purple sandstone P
23' Purple shales with bands of grey siltstone Q
76' Grey shales with a few purple bands, & grey siltstones R
28' Grey shales with thin silty bands S
32' White quartzite T

TEXT-FIG. 2.—The lithological succession is diagrammatically summarized in the left-hand column. The distribution of beds of bentonitic clay is indicated in the right-hand column.

loc. cit., p. 38) rest on a highly irregular pocketed surface of the quartzite. It is not impossible that coarse basement conglomerates of Llandovery age exist close to the site of the boring, and that the latter fortuitously encountered a minor eminence in the Cambrian land-surface, and so did not pass through these ; even so, there are indications of considerable differences in the sequence of events in the two areas.

The Llandovery beds of the boring, apart from the very thin basement bed, include practically no deposits coarser than the fine sand grade, and are mainly evenly bedded mudstones and shales. The abundant shelly fossils are almost without exception unworn ; and the only evidences of current action are seen in the grey calcareous siltstones of divisions (N) to (R), some of which show slight false-bedding, and in the current-swept pockets in the top 12 inches of the purple sandstone (P). A general picture is presented of deposition on a gently subsiding sea-floor, in which a rich brachiopod-coral fauna thrived, in well-aerated waters, but at a depth near the lower limits of wave action, and at a spot sufficiently distant from a coast line to be beyond the limits of strong coastal currents and the settlement of coarse detritus. The purple sandstone (P) may represent a slight temporary decrease in the otherwise even rate of subsidence.

It would appear that the Upper Valentian sea encroached rapidly and uninterruptedly over the Walsall portion of the Cambrian land mass, until it reached the higher ground of the Rubery area and the rapidity of the transgression decreased, allowing time for the accumulation of the considerable thickness of coarse off-shore deposits represented by the Rubery Sandstone Series. The lithology of the Upper Llandovery Sandstone of Great Barr accords with this hypothesis ; so does the abundance in the boring of *Stricklandia lirata forma typica*, which is not found in the Rubery Valentian rocks (see St. Joseph, loc. cit., p. 421)

(*b*) *Wenlock.*—" Purple Shale " conditions of sedimentation were finally replaced by typical " Wenlock Shale " conditions at the top of division (N). From this level to the top of division (F) conditions of sedimentation appear to have been remarkably constant. The only marked lithological variation is in the content of calcium carbonate, which reaches a maximum in the Barr Limestone. Throughout this 791 feet of sediment there is no sign of wave or current action. The mudstones and limestones are evenly bedded, and the latter are mostly fine-grained and of the nature of chemical precipitates. The fossils are unworn. There is a rich shelly fauna, mainly brachiopods and simple rugose corals ; but among the latter, though their numbers are great, only a few genera are represented and the aberrant *Calostylidae* are commonest ; there is no luxuriant growth of large compound reef-building rugose corals such as is found in the Wenlock Limestone, and tabulate corals occur only as small stunted colonies. Many small simple rugose corals, and also specimens of *Lingula*, occur erect in the mudstones in position of life.

These deposits bear witness to gradual, long-continued, and remarkably uniform, subsidence of the Midland "kratogenic block"; and of the gradual settlement of calcareous muds in placid waters on to a sea-floor undisturbed by current or wave action, and at a rather greater depth than that of Valentian times. At the end of Wenlock Shale times the rate of subsidence diminished; the sea-floor came within the influence of wave action, and the waters immediately above it, now well-aerated and constantly changed, no longer inhibited the growth of reef-building corals. Simultaneously the rate of deposition of calcium carbonate increased. In these shallow waters were deposited the Basement Beds of the Wenlock Limestone, which are seen at surface outcrops near Walsall to contain unbedded reef structures composed mainly of large colonial corals, as well as water-worn fossils derived from these.

BENTONITIC CLAYS.

It has been thought advisable to keep distinct from the foregoing account the description of a number of beds of clay which were noted in the Silurian rocks and which on investigation have proved to be bentonitic. It may perhaps be useful to quote the definition of bentonite proposed by C. S. Ross and E. V. Shannon.[1]

"Bentonite is a rock composed essentially of a crystalline clay-like mineral formed by devitrification and the accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash; and it often contains variable proportions of accessory crystal grains that were originally phenocrysts in the volcanic glass. These are feldspar (commonly orthoclase and oligoclase), biotite, quartz, pyroxenes, zircon, and various other minerals typical of volcanic rocks. The characteristic clay-like mineral has a micaceous habit and a facile cleavage, high birefringence, and a texture inherited from the volcanic tuff or ash, and it is usually the mineral montmorillonite, but less often beidellite."

The present investigation does not pretend to be comprehensive, and the term "bentonitic clays" is therefore used for the Walsall deposits in preference to "bentonite", since their degree of purity has not been determined. Ross and Shannon suggest that the name bentonite be confined "to material with at least 75 per cent of the bentonitic clay minerals."

Although there is an extensive American literature dealing with bentonites and bentonitic clays, which have a diversity of economic applications,[2] until recently little attention has been given to British occurrences. In many English papers dealing with Silurian stratigraphy, however, there are references to bands or "wayboards" of yellow or white clay, which will probably prove to be bentonite on petrological investigation. The "Walker's Earth" or "Walker's Soap" of Murchison,[1] may be cited as an example; Murchison records the use of this yellowish-white clay for cleansing purposes, and notes that "'Walker Erde', the German of Fuller's Earth, is evidently the origin of this provincial name". The reaction of bentonite to water is generally similar to that of Fuller's Earth. The *Lichfield Memoir* of the Survey[2] mentions that a band of clay similar to the bentonitic clays of the bore-hole was formerly worked by a shaft at Daw End, near Walsall, and offered for sale as Fuller's Earth.

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[1] "The Minerals of Bentonite and Related Clays and their Physical Properties," *Amer. Ceramic Soc. Journ.*, 1926, 9, No. 2, 79. See also C. S. Ross, "Altered Volcanic Materials and their Recognition," *Bull. Amer. Assoc. Petroleum Geol.*, 1928, 12, 143–164.

[2] See S. Spence, "Bentonite" *Mines Branch, Dept. of Mines, Canada*, 1924, pp. 1–36, 13 plates; and C. W. Davies, "Bentonite, Its Properties, Mining, and Utilization," Technical Paper 438, *Bureau of Mines, U.S. Dept. of Commerce*, 1928, pp. 1–51.

If, as seems highly probable, bentonitic clays occur in all the Silurian inliers of the Midlands and Welsh Borderland, it is likely that they will prove valuable for purposes of correlation, since in America even thin bands of bentonite have been proved to extend laterally for over a hundred miles.[3] Mr. St. Joseph is engaged on a study of bentonitic clays from some of the Welsh Borderland Silurian outcrops.

The cores from rotary borings are particularly useful for the discovery of the beds, which stand out clearly when fresh by reason of their vivid, usually green, coloration; in weathered exposures it is difficult to distinguish the thinnest bands from the normal detrital sediments in which they occur.

The distribution of the bentonitic beds in the boring is indicated in Text-fig. 2, and further details of their nature and occurrences are listed below.

	Thickness of Bed.	*Occurrence.*	*Depth below Surface.*		*Distance Below :—*	
	in.		ft.	in.	ft.	in.
					Top of Wenlock Shale	
G	1½	Green	113	3	34	3
	7	Green	195	9	116	9
H		None.				
I	1½	Mottled purple and green	607	9	528	9
J		None.				

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[1] *The Silurian System*, 1839, pt. i, 304, 434–5.

[2] *Explanation of Sheet* 154, 1919, 214.

[3] C. A. Bonine and A. P. Honess, "Bentonite in Pennsylvania," Bull. 5 Mineral Industries Experiment Station, Pennsylvania State College, *Proc. Pennsylvania Acad. of Science*, iii, 1929, 1–8. L. Whitcombe, "Correlation by Ordovician Bentonite," *Journ. Geol.*, 1932, 522–534. R. R. Rosenkrans, "Correlation Studies of the Central and South Central Pennsylvania Bentonite Occurrences," Technical Paper ii, Min. Ind. Experiment Station, *Amer. Journ. Science*, 5th Series, 1934, xxvii, 113–134.

	Thickness of bed.	*Occurrence.*	*Depth below Surface.*		*Distance below :—*	
	in.		ft.	in.	ft.	in.
					Top of Wenlock Shale	
K	½–1	Mottled purple and green with much biotite	662	10	583	10
	¼	Pale green	674	9	595	9
	⅛	Pale green	685	2	606	2
	2	Pale green	706	6	627	6
	1½	Green with much biotite	713	5	634	5
	1	Mottled green and pink	714	5	635	5
	¼	Pale green with "fucoids"	720	4	641	4
	½	Pale green with "fucoids"	721	4	642	4
	½	Pale green with much biotite	729	1	670	1
	2	Pale green with "fucoids" and much biotite	755	0	676	0
	¼	Pale green with "fucoids" and much biotite	758	6	679	6
					Top of Barr Limestone	
L	2	Pale green	766	0	4	0
	¼	Pale green	767	7	5	7
	½	Pale green with "fucoids" and much biotite	776	11	14	11
	⅛	Pale green	789	0	27	0
					Base of Barr Limestone	
M	2	Pale green	802	8	7	2
	¾	Pale green	814	7	19	1
	⅛	Pale green	822	3	26	9
	⅛	Pale green	841	0	45	6
	2	Pale green with much biotite	867	0	71	6
	¼	Green	868	4	72	10
N	1	Purple with "fucoids"	872	7	77	1
	⅛	Pale green	902	0	106	6
	⅛	Pale green	902	4	106	10
	⅛	Pale green	904	6	109	0
	1/16	Pale green	906	0	110	6
	1/16	Pale green	907	6	112	0
	⅛	Pale green	909	10	114	4
	1	Pale green	912	0	116	6
	1/16	Pale green with much biotite	912	4	116	10
	1	Pale green	915	6	120	0
	⅛	Pale green	917	0	121	6
O	¼	Pinkish green	920	0	124	6
	⅛	Pale green	921	0	125	6
	⅛	Pale green with much biotite	923	0	127	6
	⅛	Mottled green and purple	926	10	131	4
	⅛	Green	928	7	133	1
	½	Green	936	4	140	10
	⅛	Pale green	941	0	145	6
	⅛	Pale green	943	6	148	0
	1	Mauve	949	6	154	0
	¼	Green	951	0	155	6
	1/16	Whitish-green	954	6	159	0
	1/16	Pale green	958	0	162	6
	1/16	Pale mauve	965	0	169	6
	1	Mottled green and mauve	971	6	176	0
	1/16	Pale green	979	6	184	0
	1/16	Pale green	991	6	196	0

Most of the clays are pale-green to grass-green in tint, but some have a mottled purple and green, or wholly purple, coloration. They are stiff, readily fissile, and have a waxy "feel" and lustre. The clays weather rapidly on exposure; they expand and crack, their colour changes from the original green or purple to buff or yellow, and finally they degenerate into a sticky white slime. When a sample of the fresh clay is immersed in water it expands to several times its original volume, this change being accompanied by flaking and cracking, and it finally breaks down or "falls" into a fine flour-like aggregate.

The junction of the bentonitic beds with the normal shales above and below them is in every case clear and sharply defined. Many of the beds contain abundant "fucoid" markings similar in form to those which are common in the normal purple shales or grey mudstones of the Llandovery and lower Wenlock Shale. These markings stand out very clearly in the bentonitic beds, since the tubes are infilled with the grey or purple matter of the "normal" sediment. They presumably result from the transference of the latter into the bentonitic clay by boring organisms.

A few of the bentonitic beds contain flakes of biotite up to 2 or 3 mm. in diameter, in such quantity that they are obvious in hand specimen. It is interesting to note that in some such cases flakes of biotite are also common in the mudstones above the bentonitic bed for a distance up to about 1½ in. Apparently the slow rate of settlement of the biotite flakes led to the concentration of a large proportion at the top of the volcanic deposit; and the slight movements of the waters over the sea-floor sufficed to redistribute the flakes in the "normal" sediment.

Rapidity of deposition is suggested by the fact that in one instance only was a fossil found in the bentonitic beds.

Professor L. J. Wills has had eight thin sections prepared from four specimens of the clays after treatment with synthetic resin; the specimens were from the 195 ft. 9 in., 766 ft., 802 ft. 8 in., and 912 ft. levels, and in each case two sections were made, one at right angles to and one parallel with the bedding. I wish to express my gratitude to Professor Wills and also to Professor Bonine, who sent me a specimen of bentonite from the quarry at Oak Hall, Pennsylvania (No. C Bentonite of Rosenkrans, loc. cit., p. 125); this specimen has also been sectioned for comparison.

Mr. C. F. Davidson has kindly examined the sections, and writes as follows:—

"Some variation is seen in the thin sections, but all are characterized by the occurrence of an extremely fine-grained clay mineral, which forms the matrix for mineral grains averaging 0·2 mm. in diameter, but sometimes considerably exceeding this size. Of these, particles of quartz of decidedly angular outline and irregular form are common, and may in part at least be of detrital origin; in some specimens, however, no quartz occurs. The commonest of the inset mineral grains is biotite, which is frequently extensively replaced by pale colourless chlorite ; in the penultimate stages of replacement the chlorite is traversed by many parallel strings of biotite of uniform optical orientation throughout each grain. In some sections large euhedral plates of biotite are visible, these exhibiting polygonal inclusions of zircon and possibly opalite. Similar inclusions are also discernible in many minute irregular masses of chlorite in the base of the rock, suggesting that this chlorite also has been derived from a dark mica.

"A small amount of calcite, in part pseudomorphing other minerals, is seen in some sections of the clay, and in other specimens bands of infiltration quartz occur.

"Even in the most coarse-grained rock the clay mineral is of so fine a texture that under a $\frac{1}{12}$ in. (oil immersion) objective its identification could not be carried out accurately. In thin section it is seen to be of micaceous habit, double refraction about equal to that of sericite, and extinction parallel to the main cleavage. A mean refractive index determined on an aggregate of several fibres—which may, however, have been associated with other minerals in submicroscopic quantities—has been found to be $1{\cdot}547 \pm 0{\cdot}002$. This value is high for montmorillonite or beidellite of normal composition, but is within the range of these minerals when potash-bearing.[1]

"The English specimens appear to be of considerably finer texture than many of the American clays, but there is a close resemblance between the former and a slide of rather weathered bentonite from Oak Hall, Pennsylvania (Geological Survey Collection, F. 4428). The Walsall clays do not exhibit clearly the glass relief structures, such as the arcuate cracks or perlites, or the 'bogenstruktur' of volcanic ashes, which are seen in many American bentonites. The absence of apparent 'bogenstruktur' cannot, however, be taken as proof that the material is not bentonitic, for this, as in many described American specimens, is probably due to the extreme fineness of the material.[2]

"To supplement the information obtainable from the thin sections, an attempt was made to separate the heavy minerals of the clays. The only mineral apparent in the residue was biotite, which occurred in great abundance in particles up to 2 mm. in diameter. Many of these were of euhedral pseudohexagonal form, and slight local replacement by chlorite was evident in several cases. Inclusions of zircon in rod-like or polygonal shapes were clearly evident, and were never accompanied by the pleochroic haloes which commonly surround zircon inclusions in biotites from plutonic rocks. Accordingly it would appear that the biotite crystals are of volcanic origin.

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[1] Ross and Shannon, loc. cit., 96.

[2] See Bonine and Honess, loc. cit., p. 4 ; Rosenkrans, loc. cit., 128.

"The stability range of detrital biotite is not great, and consequently the mineral is an extremely rare one in early Palaeozoic sediments. Bearing in mind the frequently euhedral form and the general absence of any accompanying species of other heavy minerals, I am of the opinion that the biotite was deposited from an air-borne volcanic dust of acid or intermediate composition, and further, as in the American occurrences of bentonite, it is to this process that we must look for an explanation of the clays which enclose the biotite.

"There can be no reasonable doubt that the Silurian specimens are bentonitic clays within the definition of American authors."

The centre or centres of origin of the clays is not obvious; volcanic rocks of Valentian age are known in Pembroke and the Malverns, and at Tortworth; but evidence of Salopian vulcanicity apart from bentonitic clays is unknown nearer than in the Dingle Promontory of South-West Ireland to the west, and in Bohemia to the east.[1]

A section of one of the green shale bands which occur in the Cambrian Quartzite has been made (Geol. Survey Coll., E 17422). Mr. Davidson remarks that "this is a slightly calcareous, chlorite-bearing arkosic mudstone in which detrital quartz is present in very large quantity associated with small flakes of muscovite." These shale bands have therefore, apart from the coloration which prompted further investigation, none of the physical or microscopical characteristics of bentonite.

A Note on "Buchanan's Laterite".[2]

By J. B. Scrivenor.

In 1909 I wrote a letter to the Geological Magazine (p. 431) objecting to a statement in a review of the late Sir John Harrison's *Goldfields of British Guiana* that only products of weathering containing free aluminium hydroxide in hot moist climates should be considered as laterite. This letter led to contributions from the late J. W. Evans, T. Crook, and Sir John Harrison. It is particularly interesting now to read again J. W. Evans's remarks. In the volume for 1910, pp. 189, 190, he said he had intimate acquaintance with the material to which the name laterite was first given in the area in which it was typically developed. On p. 190 he said that laterite varies, but one feature remains constant, the small amount of combined silica in proportion to the alumina present and that "it is in this respect that laterites differ from clays, which also occur as tropical decomposition products and are sometimes incorrectly described as laterites". On p. 381 of the same volume J. W. Evans wrote: "I admit that he (Buchanan) did not know its true chemical composition, but in spite of that it must be accepted as the type of what we ought to call laterite."

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[1] J. Selwyn Turner, "Gotlandian Vulcanicity in Western Europe," Geol. Mag., 1935, LXXII, 145–151.

[2] See Fox, *Records Geol. Survey of India*, 1936, part iv.

Thanks to Dr. Fox's paper we now know the chemical composition of Buchanan's laterite, that it is characterized by hydrated aluminium silicate, not by hydrate, and that J. W. Evans and others were wrong in their assumption, without the support of any chemical analyses, that the type laterite of Buchanan is characterized by the small amount of combined silica in proportion to the alumina present.

As long ago as 1910 Sir John Harrison had recognized that generally speaking basic rocks in British Guiana gave aluminium hydrate on weathering while acid rocks gave hydrated silicate. In later years Monsieur F. Blondel, Mr. A. C. de Jongh, and myself published remarks pointing in the same direction (see *The Geology of Malaya*, ch. ix); and it really should not have been surprising to find that Buchanan's laterite, when at last submitted to the test of analysis, conforms with experience elsewhere.

Dr. Fox's paper contains an editorial introduction by Sir Lewis L. Fermor, who writes: "If Dr. Fox were possessed of the zeal shown by some systematists, who delight to upset established usage in favour of the strict application of the laws of priority often with either annoying or amusing results, he would now propose that the term laterite should be restricted to the lithomargic rocks studied by Buchanan, and that a completely new term should be adopted for the high-level laterites of the Deccan, for example." I think it has been made clear that my view about the term "laterite" is that it is of little scientific value because of the confusion that has arisen over its use; but we are now faced by the fact that the type laterite does not conform with the definition as given by J. W. Evans, and that therefore that definition is wrong. I have no inclination whatever to insist on the strict application of the laws of priority in this case, and, at the risk of being thought egotistical, will recall here what Sir John Harrison wrote in this Magazine in 1910 (p. 559): "Following Mr. Scrivenor the laterite can be conveniently classed into siliceous, ferruginous, or aluminous laterite as its components indicate, while the highly aluminous masses in them can, in my opinion, be best and most acceptably described as bauxite." I venture to think that the suggestions contained in that quotation are better than asking geologists to distinguish between "lithomargic laterite" and "lateritic lithomarge", as Sir Lewis Fermor does in his editorial introduction (p. 390).

Dr. Fox's paper is a very valuable contribution to the study of tropical weathering. As far as the word "laterite" is concerned, it appears now that even Max Bauer's Seychelle laterite is suspect (pp. 403–7); but I propose to comment on the paper now solely as a study of tropical weathering without any further reference to the use of the term "laterite".

Dr. Fox puts forward three very interesting and attractive hypotheses: that the formation of hydrated aluminium silicate in acid rocks is a stage towards the formation of aluminium hydrate, such as is found in the weathered Deccan traps; that alkaline solutions liberated in the formation of kaolin from felspars attack and dissolve the free quartz (p. 402); and that the presence of free silica acts as a preventive to the formation of hydrated alumina until all the free silica has disappeared (p. 413). I am not quite clear why Dr. Fox introduces analyses of khondalite into his paper, as I believe khondalite to be crystalline schists composed chiefly of quartz, garnet, sillimanite, and graphite, but from what he says on p. 413 I think I have construed his remarks correctly.

I have had no opportunity of examining at first hand evidence for these hypotheses in India, but abundant opportunities in Malaya, where the weathered portions of the porphyritic granite batholith are exposed in miles of road-sections and other excavations; and I find some comfort in Dr. Fox's remarks because I ventured to state in the 1910 volume of this Magazine (p. 336) that I had obtained by analysis more than 10 per cent of free alumina in weathered granite and 2 per cent in kaolin; while on p. 383 I said I had obtained over 13 per cent of alumina, which was assumed to be present as hydrate, from weathered granite. An analysis by Mr. J. R. Hill, quoted in *The Geology of Malaya*, p. 150, in some measure supported my results, but analyses by Sir John Harrison of kaolinized orthoclase crystals did not show any reason to suppose that aluminium hydrate was present (loc. cit., p. 149), and several analyses by Mr. C. Salter gave me no support (loc. cit., pp. 152, 153). All these gentlemen were far better qualified as chemists than myself, and as the weight of evidence was against me I admitted that I might have been wrong, but added: "I think the truth of the matter is that small quantities of aluminium hydrate are formed in acid rocks and in sedimentary rocks, but that without any doubt the chief weathering product in granite is hydrated silicate of aluminium closely agreeing in chemical and physical properties with kaolinite."

When writing to Dr. Fox to thank him for sending me his paper I told him I was deferring comment until I had received information about bauxite, which I believed to be over granite in the Dutch East Indies. While writing this note there has come to hand the December copy of the *Mining Magazine*, containing a paper by Dr. R. J. Anderson on "World Resources of Aluminium Ore", in which (p. 335) it is stated that in 1935 10,000 tons of bauxite were exported from the island Bintan and that preparations are being made to raise the export to 200,000 tons. Bintan and the neighbouring island Batam, both close to Singapore, are formed of Triassic sedimentary rocks with volcanic rocks of the Pahang Volcanic Series and intrusions of granite. In 1928, when in Bandoeng, Java, I was shown a specimen of bauxite from Bintan which was decomposed granite, but as yet I cannot obtain precise information about the origin of the bauxite that is being exported now. Some analyses were published in 1925 in *Indische Delfstoffen en hare Toepassingen*, No. 18, p. 36, but although called " bauxitic laterites " many of the rocks show a high SiO_2 percentage. In a letter dated 20th October, 1936, Dr. J. Zwierzycki, Director of the Afdeeling Geologie van den Mijnbouw, tells me that on Bintan, Batam, and Banka the bauxite deposits cover granite as well as different types of sedimentary rocks.

More important scientifically is another paper lent to me by Professor J. H. F. Umbgrove, of the Technische Hoogeschool, Delft. This is " Bauxit und Laterit auf Banka ; Ein Beitrag zur Kentniss der Geologie von Banka," H. W. Junker, *De Ingenieur in Nederlansch-Indië. IV, Mijnbouw en Geologie.* De Mijningenieur. February, 1936, Bandoeng, Bragaweg 38. In this paper Junker gives twenty-two analyses of Banka specimens and others of specimens from the islands Bintan and Batam of the Riau Archipelago, some of which are repeated from the 1925 paper.

Of the Banka analyses Nos. 12–16 are of " Siallit ", hydrated silicate clays ; 17 and 18 are of " half-bauxitized granite " mesh—100, with silica in excess of alumina ; 19 is an iron-rich laterite ; and 20–22 are of shaly bodies at various depths, all with more silica than alumina.

Nos. 1–11, however, are of specimens in which the alumina is far in excess of the silica, the most interesting being analyses of pseudomorphs of bauxite after felspar from granite. These are transcribed below :—

	I.	II.	III.	VIII.	IX.
	%	%	%	%	%
SiO_2	4·61	7·55	5·39	1·70	5·08
Al_2O_3	60·79	59·32	59·16	65·80	62·57
Fe_2O_3	2·47	1·98	3·59	0·67	0·63
TiO_2	n.d.	n.d.	0·20	n.d.	trace
$H_2O +$	31·89	30·63	31·42	31·56	32·15
$H_2O -$	0·39	0·46	0·34	0·31	0·40
Total	100·15	99·94	100·10	100·04	100·83

I. Felspar pseudomorph, Tempilang, Banka.
II. Felspar pseudomorph, Tempilang, Banka.
III. Felspar pseudomorph, Batu Balei, Muntok, Banka.
VIII. Felspar pseudomorph from tin-bearing sand, Mine 4, Muntok, Banka.
IX. Felspar pseudomorph from tin-bearing sand, Mine 9, Muntok, Banka.

Of the other analyses IV and V are of specimens from granite country ; VI and VII of specimens from shale country ; X and XI are of lumps from sand.

I was in Banka in 1926, but only for five days, and as Banka is an island about the same size as Wales I did not see very much, though conducted by the staff of the Banka Tinwinning to the most interesting localities. The general weathering of the granite, however, seemed to be to a kaolin-clay as in Malaya, but there is no reason whatever to question Junker's bauxite pseudomorphs of orthoclase—

they are in fact figured in the paper. Whether they are abundant and whether there is much aluminium hydrate formed from granite remains to be seen. What matters now is that the analyses show that porphyritic crystals of orthoclase can be converted by weathering almost entirely to aluminium hydrate. No such alteration has been proved in the Malay Peninsula, but Junker's analyses are further comfort to me in connection with my humble efforts in 1910. They can also be taken as support for Dr. Fox's hypotheses quoted above; but concerning these Dutch East Indies bauxites there is a lot to be learned yet. There are three possible sources at least, granite, Triassic shaly rocks and phyllites, and the Pahang Volcanic Series, which ranges from rhyolites to basalts. Perhaps some of the Dutch bauxite corresponds to the material over schists in Kinta, rich in aluminium hydrate, particularly well developed near Pusing; we must wait for further information.

Although the bauxite pseudomorphs of orthoclase are in favour of Dr. Fox's hypotheses, I fear the latter are open to objection on other grounds.

The first hypothesis is that the hydrated silicate of aluminium is only a stage towards the formation of the hydrate. The question arises, how long are we to wait for the hydrate? In Malaya there is good reason to believe that the granite ranges have been exposed to denudation at least since early Pleistocene times, but there is no evidence of a general formation of hydrate from the kaolinized felspars. Denudation is always active of course, but it is also active in the Dutch islands. Moreover, in low-lying parts of Malaya where kaolinized granitic rocks are exposed and where denudation is less active, no general change to hydrate has been noted. If Dr. Fox is right in considering kaolinization as only a stage towards formation of the hydrate surely somewhere in Malaya there should be a bauxite deposit formed from granite?

The second hypothesis is that alkaline solutions liberated from the kaolinized felspar dissolve the free quartz, and in the third hypothesis, that they return and attack the kaolin after dissolving all the free quartz. The first objection to these propositions is that it is reasonable to assume that the alkaline solutions would first attack the nearest victim, namely the kaolin. The second is that large outcrops of quartzite, with quartz cement, in Malaya, are weathered back to sandstone by solution of the quartz cement and in that case there is no question of alkaline solutions from kaolinized felspar. Ground water at about 80° Fahr. with much humic matter in solution is the agent that dissolves the quartz and that also is probably the agent that dissolves the free quartz to some extent in Malayan granite. Moreover, in Malaya, and I suspect in India, rainfall is so heavy that the alkalis from felspar would be washed away entirely before they could dissolve all the quartz in weathered granite. Orthoclase can only yield a limited amount of alkali in solution and tropical showers will soon wash it into the sea. On low ground, where ground-water percolates more slowly than on hill-ranges, alkaline solutions would have a longer time to act, but they do not appear to have yet attacked the kaolin to form hydrate in noticeable quantities.

Nevertheless, Dr. Fox's hypotheses are both interesting and attractive. I think that it is simpler at present to recognize the two forms of weathering of felspars as end-products, with some exceptions such as those noted above, hydrated silicate from potash-soda felspars and hydrate from soda-lime felspars, but future work may show that Dr. Fox is right in thinking that the formation of hydrated silicate from potash-soda felspars is only a step towards the formation of hydrate.

The Rocks of the Kedong Scarp, Kenya Rift Valley.

By S. J. Shand.

In a communication to the Geological Magazine, published in July, 1936, I gave a brief description of the rocks that build the Kedong scarp. I propose now to amplify that description. It is not always realized that the geological structure of the Rift Valley has been deduced almost wholly from physiographic evidence, and that proof of the alleged displacements must depend upon exact petrographic study of the rocks involved in the structures.

The Kedong scarp may be described as that segment of the Kikuyu scarp which has been cut back by the headwaters of the Kedong River; it forms a wide embayment extending from Kijabe Hill (latitude 0° 55′ S.) to a point due west of Limuru (lat. 1° 7′ S.). My observations cover four groups of rocks, as follows :—

(*a*) The trachytic lavas and tuffs that form the upper nine-tenths of the scarp ;

(*b*) The porphyritic olivine-basalt that forms the base of the scarp ;

(*c*) The syenite-porphyry that forms the rim of the Kijabe terrace ;

(*d*) Enclosures in the Kijabe tuff.

The simplest way of fixing positions on the scarp is to refer to the altitudes and distances of points on the railway line. The altitudes of the three railway stations are : Uplands, 7,689 feet ; Escarpment, 7,391 feet ; Kijabe, 6,787 feet. Points between these stations are easily located by reference to the mileage (measured from Mombasa) which is recorded on the telegraph posts along the track.

Near Uplands station weathered trachyte is exposed in cuttings about mile 362. Between Uplands and Escarpment the cuttings and banks show only a great thickness of red soil. Near Escarpment station grey trachyte appears on the hill tops, and the station is built on a broad terrace cut in this rock. From here down to T.P. 370–12 soft decomposed trachyte is exposed in the cuttings; comparatively fresh specimens were collected at 368–22 and 369–22. The cutting at 370–12 is in a pebbly and in part pisolitic tuff, of which a considerable thickness is exposed in the gorge spanned by a bridge at mile 371. At 371–5 a strongly porphyritic grey trachyte appears. The deep gorges and cuttings about mile 372 show only talus and landslip. The cutting at 372–5 is in pebbly tuff with thin intercalations of trachyte. This locality is directly beneath the terrace upon which the Rift Valley Mission is built. On the terrace itself and on its flanks there are no natural exposures of rock, owing to thick soil and forest, but sections exposed in the road that climbs up to the Mission show trachyte-tuff with some thin and much decomposed flows of trachyte.

From T.P. 372–5 down to Kijabe and beyond it to T.P. 373–18, only pebbly tuff is seen in the cuttings. This is the tuff in which the Kijabe terrace is cut, as described in my previous communication. From T.P. 373–18 to beyond 375–12 a strongly porphyritic olivine-basalt is the only rock exposed; it forms the base of Kijabe Hill and eventually disappears beneath the rising floor of the rift-valley before the railway-crossing near Longonot is reached. The same rock underlies the tuff in the Kijabe terrace.

If there is no faulting and duplication of beds in the section between Escarpment and Kijabe, then the thickness of the various groups must be of the following order:—

Upper trachyte division .	350 feet	(*plus* an unknown thickness above Escarpment station)
Upper tuff division .	60 ,,	
Second trachyte division .	50 ,,	
Kijabe tuff . . .	200 ,,	(of which 50 feet below the level of Kijabe station)
Olivine-basalt . .	100 ,,	(*plus* an unknown thickness beneath the floor of the valley)

PETROGRAPHY.

The *trachytes* have essentially the same characters throughout the entire height of the escarpment between Uplands and Kijabe, and along the strike from Kijabe to Limuru at least. I was not able to examine the escarpment between Limuru and Ngong, but somewhere in that region the trachytes give way to phonolite, which is the dominant lava in the Ngong region. Dr. Prior, who studied Professor Gregory's collection of rocks, called the Kedong rocks "phonolitic quartz-trachyte", and this terminology was followed by Gregory himself and by Miss Neilson and Professor Lacroix. Seeing that none of these trachytes carries any feldspathoid, that all of them carry quartz, and that true phonolite occurs in the neighbourhood, I think the use of the adjective "phonolitic" was unhappy. It was apparently intended to indicate the presence of soda-pyroxenes and soda-amphiboles in the trachytes, although these minerals are not peculiar to phonolite. Dr. Prior recorded aegirine-augite, cossyrite, and cataphorite in the specimens examined by him, and Miss Neilson observed aegirine and diopside as well.

My specimens, taken at many points on the escarpment, are all very much alike. They differ chiefly in crystallinity, the thinner flows having a spherulitic groundmass while the thicker ones have a "trachytic" groundmass composed of laths of alkali-feldspar with interstitial quartz. The rocks are moderately porphyritic, with insets of anorthoclase from 2 to 5 mm. in diameter; but the rock exposed in the railway-cutting about T.P. 371–5 has conspicuous insets, many of which are over a centimetre in diameter. Measurements of the optic axial angle gave values about 50°, which is within the range of anorthoclase. The dark minerals are entirely interstitial, forming shapeless scraps and sponge-like masses all through the groundmass. The most prominent of these is a dark brown hornblende having pleochroism to yellow-brown, with an extinction angle of about 30°. It is hardly possible to make a satisfactory study of the optical properties of these ragged scraps, so I am not prepared to say which of the numerous varieties of soda-hornblende they represent. A bright green mineral forming tiny prisms and shapeless scraps is much less abundant than the brown hornblende. It has straight extinction, with X parallel to the length of the prisms, and it is distinctly pleochroic from emerald-green to yellowish-green. These characters indicate aegirine. Some olivine is present in most slides; it has a yellowish colour in thin section and it alters into limonite instead of serpentine, so it is probably pure fayalite. The grains are so few and so small that I was unable to measure any of the optical constants. Magnetite and a little apatite are present, too. When a section is treated with dilute acid and dye the colour is taken up quite strongly in the interstices of the groundmass, but I am satisfied that this is due to colloidal weathering-products. None of the rocks can be described as perfectly fresh, for they have a high porosity and the rainfall on the upper slopes of the escarpment is very heavy.

The freshest of all my specimens is one that I collected at the south end of the Kijabe embayment, where Sclater's road makes its last steep descent to the floor of the valley. This rock was analysed for me by Mr. J. S. van Zyl, a senior student in my department, with the result given on p. 265. Professor Lacroix has given an analysis (by F. Raoult) of a "phonolitic trachyte" from the Kikuyu escarpment which is closely comparable with my rock and may have been collected from the same exposure.[1]

It will be noticed that acmite does not appear in the norm, although aegirine is actually present in the rock. An analytical error might have been suspected, were it not that Raoult's analysis shows the very same peculiarity. The explanation is, I suspect, that there has been some natural leaching of soda from the rock; this idea is supported by the presence of colloidal weathering-products in the interstices, as already mentioned.

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[1] A. Lacroix, *Minéralogie de Madagascar*, iii, 1923, 258. See also W. Campbell Smith in *Quart. Journ. Geol. Soc.*, 1931, 220.

SiO_2	64·45
Al_2O_3	15·79
Fe_2O_3	3·81
FeO	2·66
MnO	·20
MgO	*trace*
CaO	·77
Na_2O	5·16
K_2O	5·51
TiO_2	·71
P_2O_5	*trace*
H_2O −	1·06
H_2O +	·68
	100·80

Norm.	
Qz	11·34
Or	32·80
Ab	43·49
An	3·61
Fs	·92
Mag	5·57
Il	1·37

Norm symbol, 1, 5, 1, 3 (Phlegrose)
Niggli type : nordmarkitic.

Trachyrhyolite, Kedong scarp. Analyst, J. S. van Zyl.

To call this rock a phonolitic trachyte is to invite misunderstanding. Its composition places it between trachyte and rhyolite, not between trachyte and phonolite. In my terminology it is a *peralkaline trachyrhyolite*, symbol DOkβi.[1]

The *olivine-basalt* which forms the base of Kijabe Hill and underlies the tuff in the Kijabe terrace is a very striking rock in the field. On the weathered, vesicular surface the only prominent mineral is plagioclase feldspar in thin plates that are often more than an inch in diameter. These insets are so abundant that at a first glance they seem to make up about half of the rock. Between them is a dense groundmass, brown on weathered surfaces but black within, in which an occasional grain of augite or olivine may be detected. The vesicles contain only films of limonite and sometimes tiny rosettes of calcite. In the less vesicular parts of the rock the insets are smaller and less numerous, but they always remain the most conspicuous elements of the rock.

The insets of plagioclase have the composition of medium labradorite. Two of them were studied on the universal stage; one proved to be an albite twin with An_{60}, the other an albite-Carlsbad complex with An_{65}. They are generally free from inclusions except in their outermost zones. Insets of augite and olivine are much smaller and much scarcer; they number perhaps one to every ten feldspars. The augite is the usual purplish-brown variety of very basic rocks. The olivine has an optic axial angle of 80–82° in yellow light, indicating about 37 molecules per cent of fayalite.

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[1] These symbols were explained in Geol. Mag., LXXII, 1935, 89.

The holocrystalline groundmass consists of plagioclase laths and tiny prisms of purplish augite, with black ore grains scattered over all. Idiomorphic olivine crystals are not at all common and are generally too large to be considered part of the groundmass; they are really small insets. Ilmenite forms large plates as well as scattered grains, and there is an unusual quantity of apatite prisms which tend to be grouped about these plates of ilmenite. The plagioclase laths seem to have nearly the same composition as the insets, although the exact determination of extinction angles is made difficult by the thinness and the irregularity of the twinning lamellae and their wavy extinction. The maximum extinction angle in sections normal to the second pinacoid is about 27°, indicating not less than 50 per cent of anorthite. Several attempts were made to investigate these laths on the universal stage; the results were unsatisfactory, but so far as they go they indicate between 50 and 60 per cent of anorthite.

The relatively high content of soda and potash shown by chemical analysis suggested the presence of an alkali-feldspar in the groundmass. Close search shows that there is certainly a little of a substance with low refraction and birefringence in the groundmass, but it appears to be zeolitic rather than feldspathic. Some parts are definitely fibrous and might be natrolite; others have the irregular birefringence of analcime. When a section is treated with acid and dye quite a lot of coloration takes place. It is probably due to colloidal weathering-products as well as zeolites, for I failed to find any nepheline.

The chemical composition of this rock is as follows:—

SiO_2	46·74
Al_2O_3	18·88
Fe_2O_3	3·11
FeO	7·15
MnO	·18
MgO	3·16
CaO	9·30
Na_2O	4·17
K_2O	1·67
TiO_2	2·44
P_2O_5	1·29
F	·11
CO_2	·16
H_2O −	1·07
H_2O +	·63
	100·06
less O = F	·05
	100·01

Norm.	
Or	10·01
Ab	28·82
An	27·52
Ne	3·69
Di	7·58
Ol	8·08
Mag	4·41
Il	4·56
Ap	3·25
$CaCO_3$	·30

Norm symbol: 11, 5, 3, 4 (Andose).
Density: 2·917 at 4° C.

Olivine-basalt, Kijabe Hill. Analyst, S. J. S.

The norm gives a fair picture of the mineralogical composition of the rock, except that the figure for olivine is too high and that for augite (diopside) correspondingly low. The molecular proportion of anorthite in the feldspar works out at 57·5. The direct measurement of the proportions of the various minerals is difficult owing to the fine grain of the groundmass. The following figures were obtained by combining micrometric measurements with computations based on the chemical analysis.

MODE OF THE KIJABE BASALT.

plagioclase	insets	35	per cent by volume
	groundmass	35	,, ,,
zeolites		5	,, ,,
augite		12½	,, ,,
olivine		2½	,, ,,
iron ore		6½	,, ,,
apatite		3½	,, ,,

Colour index, 25.

When one attempts to classify this rock by the mineralogical method, the chief difficulty is to decide whether the zeolitic matter is primary or secondary. If any of it is primary or has been formed by transformation of nepheline, then the rock is a basanite; but if the zeolite was formed at the expense of feldspar, as is most probable, then the rock is a leucocratic olivine-basalt. Or again, if the colour index were generally accepted as the means of distinguishing andesite from basalt, the rock would be called an olivine-andesite. To avoid misunderstanding I shall continue to call it olivine-basalt, though it is obviously an abnormal type. I have attempted to place the rock in Professor Niggli's classification, but I find myself unable to decide which magma-type to refer it to. I give below the Niggli symbols of the Kijabe rock and of the most nearly comparable magma-types.

	si.	*al.*	*fm.*	*c.*	*alk.*	*k.*	*mg.*
Kijabe basalt	119	28	33	25	13	·21	·36
Ossipitic type	110	28·5	34·5	28·5	8·5	·12	·60
Gabbrodioritic type	135	24·5	42·5	23	10	·28	·50
Essexitgabbroid type	105	23	43	24	10	·25	·45

The interesting problem of differentiation presented by the Kijabe basalt, and its relation to the "augitite" of Ngong, will be discussed in the concluding section of this paper.

The *syenite-porphyry* that forms the rim of the Kijabe terrace (see my previous communication) is a coarse, grey rock that weathers into great rounded boulders like a granite. It is impossible without blasting or quarrying to get really fresh material for study. The rock is mainly composed of orthoclase in crystals that range from several centimetres down to a few tenths of a millimetre in diameter. Feldspathoids are absent, but there is a small quantity of quartz in the groundmass of the rock. The heavy minerals include pale green diopside, forming perhaps 5 per cent of the rock; a little apatite and zircon, and abundant iron oxide, much of which is secondary. Some of the latter has been formed by the alteration of a deep brown barkevikitic hornblende, of which a few grains are still to be found in the rock.

The junction between this rock and the Kijabe tuff (with thin trachyte flows) is exposed in the flanks of the Kijabe terrace. I was unable to decide whether it is an intrusive contact or a faulted junction, but I suspect the latter.

The mineralogical resemblance between this porphyry and the trachytes of the escarpment is so considerable as to suggest that the porphyry occupies one of the vents or fissures from which the trachyte was extruded. If so, it may lie on or close to the main eastern fault of the rift-valley. Unfortunately the extension of the porphyry beneath the floor of the valley cannot be traced for lack of exposures.

The *enclosures* in the Kijabe tuff include two kinds of eruptive rock. One is a structureless black obsidian, the lumps and flakes of which are fairly numerous, although not all of them are enclosures. Kijabe seems to have been the site of a stone implement industry, and the larger lumps of obsidian that lie about on the surface of the terrace may be cores rejected by the implement makers. These lumps may therefore have been brought to Kijabe from the field of obsidian at the south end of Lake Naivasha.

Of greater interest to me was a single boulder, weighing about 2½ lb., of a basic rock that I dug out of the tuff near the margin of the terrace. The exposed surface of this rock is light grey, studded with black crystals of augite and hornblende. A freshly broken surface is perfectly black except for a few brown specks of altered olivine. The density of the lump is 2·98.

This rock proves to be identical in every essential respect with the "augitite" of Ngong, some 25 miles southward. I cannot visualize any process by which this boulder could have been transported from Ngong to Kijabe, so I conclude that it was thrown out by one of the volcanoes which furnished the trachyte-tuff. If so, it shows that "augitite" of the Ngong type underlies the Kijabe basalt. The significance of this observation will be discussed in the next section.

Under the microscope the rock shows an abundance of idiomorphic crystals of purplish or brownish augite ($2V = 50°$, $c \wedge Z = 45°$) with some larger pieces of marginally resorbed hornblende, a few small crystals of olivine (largely changed into iddingsite), and some ore grains; all of these lie in a fine-grained basaltic groundmass composed of labradorite laths and tiny grains of augite and ore. There may be a little analcime in this groundmass, and there is a small amount of chalcedony lining cavities.

The close correspondence between this rock and the Ngong augitite is shown by the following figures, which are based on micrometric measurement of the insets and eye-estimation of the groundmass constituents.

		Kijabe.	*Ngong.*
insets	augite	16	13
	hornblende	4	4
	olivine	1	scarce
	ore	5	3
groundmass	plagioclase (An_{50-60})	30	35
	ore	10	10
	augite, apatite, etc.	34	35
	colour index	70	65

A chemical analysis of the Ngong "augitite" was made by W. H. Herdsman for Mr. Campbell Smith[1]; that analysis may serve to indicate the chemical character of the Kijabe specimen, too, although it appears from Miss Neilson's description[2] that the analysed rock (one of Professor Gregory's specimens) was not quite identical with the specimens that I collected in the same neighbourhood.

Clearly the name "augitite" gives a very inadequate picture of these rocks, and "nephelinite" (used by Mr. Campbell Smith) is not applicable to my specimens. They are simply melanocratic basalts, containing the same minerals and having the same groundmass as the Kijabe basalt, from which they differ only in respect to the colour index (70 against 25).

The Differentiation of the Basalt and the "Augitite".

The insets of labradorite in the Kijabe basalt average 15 mm. in length, the groundmass feldspar about 0·3 mm., so the insets are about fifty times as large as the groundmass feldspars. What makes this contrast specially striking is that feldspar crystals of intermediate size are quite scarce. One gets the impression that the insets are not just the "big brothers" of the little crystals but their stepbrothers. Even more remarkable than the size of the insets is their abundance, amounting to 35 per cent of the volume of the rock. It seemed to me, when I examined this rock in the field, that there was a connection between the abundance of plagioclase insets and the vesicularity of the rock; the more vesicles the more insets. This observation led me to speculate upon the capacity of *gas flotation* to bring about a concentration of feldspar crystals in the upper part of a lava flow. The insets are conspicuously thin—a typical example measured 15 × 15 × 1 mm.—so they have a very large surface in proportion to their bulk and mass. The augite insets are more nearly equidimensional (for instance, 3 × 2 × 1 mm.), hence an augite crystal must have some three times the bulk of a feldspar of the same surface, and about four times its mass. I think it not unreasonable to suggest that the rising gas bubbles, either by attaching themselves to the growing feldspar crystals or perhaps by simple " bumping ", may have helped to concentrate the big feldspars in the upper part of the lava flow. The augite crystals would hardly be affected by this process, partly because of their greater density and partly because they seem to have begun their crystallization somewhat later than the feldspar.

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[1] *Quart. Journ. Geol. Soc.*, lxxxvii, 1931, 254.

[2] J. W. Gregory, *Rift Valleys and Geology of East Africa*, p. 403.

It is usual, I know, to refer all such phenomena to the action of gravity, but the evidence in the case of feldspar is contradictory. There is indeed a strong difference of opinion among petrologists as to whether the early crystals of plagioclase in a basic magma will sink or swim ; N. L. Bowen may be cited as the protagonist of one view and F. F. Grout of the other. An instance of the concentration of plagioclase at the *base* of a lava-flow was recorded by Charles Darwin in the Galapagos Islands.[1] When the effect of gravity is so problematical, the hypothesis of gas-flotation seems worthy of consideration.

Among the Carboniferous basalts of Scotland the Markle type holds big insets of labradorite, and W. Q. Kennedy has shown that in some instances this rock forms the vesicular top of a composite lava-flow.[2] I can find no general statement as to the position occupied by the "big felspar basalts" of Mull, but there is one reference to the "thick slaggy top" of a flow of this kind.[3]

But whether gas-flotation or gravity was the active agent, the fact remains that there is an entirely abnormal concentration of large plagioclase crystals in the vesicular top of the Kijabe basalt sheet. The abnormality is indicated not only by the number and size of the insets, but by the " stepbrother " relation to which I have alluded. If the magma was sufficiently fluid to permit the feldspar crystals to float upwards, it must also have permitted the heavier augite crystals to gravitate downwards. Olivine would sink, too, but olivine is never abundant in these rocks and the crystals are relatively small. Thus while the upper levels of the basalt became enriched with feldspar, the lower levels might be enriched with augite. Now if the Kijabe basalt is the result of the former process, the Ngong " augitite " is exactly what one would expect to result from the second process. My chance discovery of a boulder of " augitite " in the Kijabe tuff seems to show that such a rock actually does underlie the Kijabe basalt, perhaps constituting the lower part of the same flow.

It is easy to show, on paper, by means of computations based either on the modes or on the chemical analyses of the two rocks, that the transference of a certain amount of labradorite from the Kijabe basalt to the Ngong " augitite ", and of augite in the reverse direction, would bring both rocks very nearly to the same composition. I attach little importance to such calculations, since one does not know the quantities involved. But I find it difficult to believe that two chemically different magmas should have reached the same end-stage (groundmass) by shedding in one case a great excess of labradorite crystals and in the other an almost equal excess (by weight) of augite and hornblende crystals. That could only happen if the groundmass were a eutectic mixture of all the minerals involved in the rock; and the reasons why one cannot regard basalt as a eutectic system are too well known to need recapitulation.

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[1] *Geological Observations*, chap. 6.
[2] GEOL. MAG., LXVIII, 1931, 167.
[3] Tertiary Geology of Mull, *Mem. Geol. Surv.*, 1924, 103.

In short the mineralogical and chemical relationship between the Kijabe basalt and the Ngong "augitite" is such that both rocks may have been derived from the same magma by the flotation of the early plagioclase crystals and the concurrent sinking of early crystals of augite and hornblende.

I hope this little study may help to reawaken interest in the petrology of what is surely the most remarkable lava-field in the world. I shall send a set of the specimens I have described to the Natural History Museum, South Kensington.

The Geology of the British Solomon Islands Protectorate.

By R. J. A. W. Lever.

SINCE the publication in 1887 of Dr. H. B. Guppy's book (1) [1] very little has appeared on the geology of the Solomon Islands, and Cowper Reed's book (2) of 1921 is based on Guppy for this area. During the last four years a small representative collection of rocks has been sent to the British Museum (Natural History) and examined by Mr. W. Campbell Smith, to whom the author is much indebted for their identification.

This article collects in one place a description of the rocks from most of the islands of the Protectorate, including areas from which specimens had not previously been collected. The author is unaware of any geological survey being carried out, except for certain parts of Guadalcanal where gold prospecting is in progress and such details of the formations are naturally not available for publication.

The Solomon Archipelago consists of a double chain of islands lying along a north-west to south-east axis and extends some 600 miles. Bougainville, the most northerly and lofty island, is a portion of the Mandated Territory of New Guinea, while the remaining six large islands and the many small ones form the British Solomon Islands Protectorate. The extreme eastern limits of this dependency are two minute islands lying 200 miles east of the Santa

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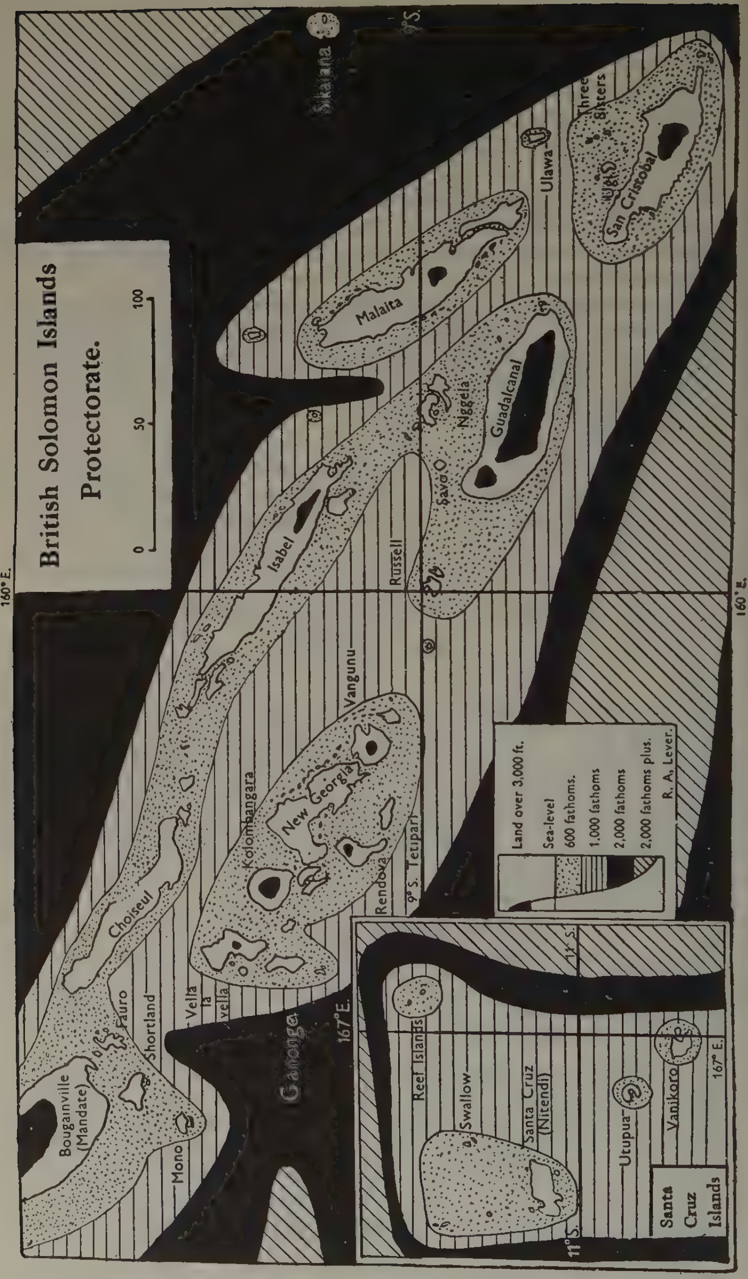
[1] The numbers in parentheses refer to list of References at end of article.


British Solomon Islands
Protectorate.
0
50
100
160° E.
160° E.
Sikaiana
9° S.
Malaita
Ulawa
Three Sisters
San Cristobal
Guadalcanal
Nggela
Savo
Isabel
Russell
Vangunu
New Georgia
Kolombangara
Tetipari
Rendova
9° S.
Choiseul
Fauro
Shortland
Vella la vella
Ganonga
167° E.
Bougainville (Mandate)
Mono
Land over 3,000 ft.
Sea-level
600 fathoms.
1,000 fathoms
2,000 fathoms
2,000 fathoms plus.
R. A. Lever.
11° S.
Reef Islands
Swallow
Santa Cruz (Nitendi)
Utupua
Vanikoro
167° E.
11° S.
Santa Cruz Islands

Cruz group, which in turn is separated by the same extent of very deep sea from the Solomon Islands proper, which extend for 500 miles to the boundary of the Mandated Territory formerly under German administration.

The whole region has been greatly elevated within geologically recent times, and deposits formed at a depth of 12,000 feet were seen by Guppy (1). On the large island of Guadalcanal are raised coral-masses now several miles inland and covered with dense jungle; corals and mollusc shells occur in these raised reefs, which are indistinguishable from those at the breakers' edge. In the Russell Islands evidence of successive elevations is seen in tiers of coral now forming headlands. Similar proof is to be found on the northern coast of New Georgia, where a barrier reef, called the Marovo Lagoon, shows similar phases of elevation. This phenomenon is believed to be of early Tertiary age, but so rapid has been the tropical sub-aerial denudation that calcareous deposits are now rarely found at a greater height than 500 to 600 feet above sea-level.

Underlying these calcareous deposits are rocks of entirely different character, composed of foraminiferal and pteropod oozes similar to some of those obtained elsewhere in the Pacific by the *Challenger* Expedition from deep soundings.

The islands will now be treated in some detail proceeding from the north-west boundary to the remote Santa Cruz group.

The core of Shortland Island is of quartz-diorite and epidotized tuffs overlaid by soft pteropod and foraminiferal material, which in turn is capped by harder calcareous rock. The islet of Poperang has a distinctive hard grey limestone with remains of *Rhynchonella*. Fauro, to the north-east, is more complex in structure, having dolerite and diorite with stumps of ancient volcanic cones of hornblende- and augite-andesite and quartz-porphyry. Mono (Treasury) has a core of dolerite covered with stratified foraminiferal material which Guppy showed to have been formerly submerged to a depth of 1,800 fathoms and, as the summit is now 1,200 feet high, there must have been a total elevation of 12,000 feet. Immediately south, and separated by no greater depth than 62 fathoms, is the small Stirling Island composed entirely of coral limestones and clearly the summit of a submerged peak.

Choiseul, for all its length of 80 miles, is virtually unknown geologically as nothing more than pteropod, foraminiferal, and coral limestone have been reported (1 and 2).

South of Choiseul lies Vella Lavella, which with Savo, to be described later, is the most thermally active island, with deposits of native sulphur, fumaroles, and solfataras. Narovo, or Simbo (the Simbi of Reed (2)), also has fumaroles as well as solfataric craters and boiling springs. The core is of pyroxene-andesite, though the backbone of the middle of the island and of Simbo to the south-east is of coral. Ganonga—lying between Vella and Narovo—has terraces marking former sea-levels at heights of 400, 800, 1,200, and 1,600 feet (1). Rocks found here are pyroxene-andesites and olive-green tuffs.

Only the southern part of Kolombangara has been visited by the author, and all the rocks were of pyroxene-andesites, which also compose the nearby islands of Rendova and Vella Lavella. Pagden (3), in dealing with Kolombangara, mentions "coral appearing as if subjected to volcanic action", but examination of the site in question shows the coral to be of subsequent formation to the andesite and is simply much weathered. The main island of New Georgia to the east also has andesites, but with augite, hypersthene, and hornblende; in addition, augite-trachyte, and olivine-basalt are present. The source of this information is a paper by Watts and Newton (4) describing rock-specimens taken on the Admiralty survey of 1893–5. Tetipari or Montgomery Island to the east of Rendova (Hammond Island) has both foraminiferal and volcanic muds, the former being found by Guppy in the interstices of the coral blocks on the foreshore.

Isabel (Santa Ysabel) is 115 miles in length, and so is one of the longest islands; Guppy does not mention it, and Cowper Reed (2) merely states that serpentine occurs. The writer has, in addition, collected red and green jaspers and chert, barytes, and limestone varying in colour from cream to drab. Associated with this in the Bugotu district are fine-grained argillaceous sandstones, and a coarse-grained gabbro. Stalactites and calcareous tufa also occur; there is a fringing reef off part of the northern coast. The islands of Banika and Pavuvu, together known as the Russell Islands, have coral inland for a mile in places, but the core is of basalt and tuff, which weathers into a fine red-brown loam bearing coco-nut palms which yield up to a ton of copra per acre. An analysis of this soil was made by the Imperial Institute and is published elsewhere (5).

Guadalcanal has the greatest area of any island in the Protectorate, viz. 2,500 square miles, which is equal to the West Riding of Yorkshire. In the south-west the mountains reach a height of over 8,000 feet, and it was in attempting to scale them that a party of Austrian geologists was massacred in 1896. This island is said by Reed (2) to possess active volcanic zones, but this is incorrect, and is doubtless due to following Darwin (6), whose map shows an active volcano on the eastern end. The only volcano in the Protectorate is 400 miles to the east on Tinakula. The plutonic rocks of supposedly Cretaceous age include biotite-granite, quartz-diorite, ophitic dolerite, epidiorite, and uralitized gabbro with volcanic andesite. Specimens from Kaukau are strongly foliated hornblende-gneiss and a serpentine similar to that from Isabel Island. White to yellow limestones occur and are of pure coral or mixed with sandy volcanic material. From Ruavatu in the eastern portion pelecypod shells and *Pholas* borings were found in an exposure of travertine. Immediately south of Savo Island and some 10 miles inland on Guadalcanal is a hot sulphur spring, the water of which was found by means of a portable Comparator outfit to have a pH of

7·4, i.e. just on the alkaline side of neutrality. It is regarded as of therapeutic value by natives who come for many miles to treat their rodent ulcers. No reference can be found in the literature to hot springs on this island, though these have been known for over half a century on Savo to the north.

The circular island of Savo was in eruption when the Solomon Islands were discovered in 1568. The base of the crater is at a height of 1,000 feet and crystals of sulphur may be found in the vicinity of steaming vents where the ground is unpleasantly hot. Woodford, who ascended to the crater in the late 'eighties, states (7) that the eruptions (the last was about 1847) were due more to imprisoned steam than to fire and he mentions his failure to find signs of recent lava streams which agrees with the experience of the writer. The Spaniards, in the sixteenth century, mention "a volcano in the middle of the island which is continually emitting great smoke" (1, p. 209). Several fumaroles occur, that on the south-east being easily accessible from the coast. Dense clouds of sulphurous vapour rise from the boiling water and these no doubt have altered the hornblende-pyroxene-andesites to be found in the vicinity.

Nggela or Florida consists chiefly of granulites among the metamorphic rocks with altered gabbro overlain by andesitic tuffs. The small island of Tulagi has a fine-grained buff-coloured clay with sponge spicules and radiolarian tests; on Gavutu are siliceous deposits, and on Bungana an olive-brown pumice has been taken.

Malaita is not mentioned by Guppy, and Reed says, only too correctly, that its geology is unknown. This lack of information is attributable to the well-deserved reputation for hostility until recently borne by its inhabitants. These notes on some of the rocks are believed to be the first published on this island of over 100 miles in length. An ophitic olivine-bearing gabbro and dolerite occur as well as brown and dark green jaspers similar to ones from Isabel. From Auki and Maka the rocks are white, compact, chalky limestones. A dark brown flint or chert is also present as well as an earthy green chlorite. Marcasite occurs in the north and tufa and basalt are abundant in the south at Maka, where a passage divides the island into two as is the case on Nggela, Russell Islands, and western New Georgia.

East of Malaita is Ulawa Island, where a dark purple weathered basalt and trachyte are found as well as a series of chalky limestones varying from a buff compact type to a pale grey crystalline one. An amber-coloured chert and a pale brown chalcedony also occur.

Immediately south of Ulawa is the large island of San Cristobal, which was thoroughly examined by Guppy and found (1) to be of much altered and very ancient rocks often of crystalline structure. Diorite, gabbro, and dolerite occur, the last often with specks of pyrite; the volcanic rocks are represented by porphyritic and compact basalts. The oldest sedimentary rocks are quartzites, clays, and slates, the youngest include limestones, often with veinlets, varying in colour from white through cream and fawn to dark red. Despite an altitude of over 4,000 feet on the island Guppy never found calcareous formations at a greater height than 500 feet. The writer has also found brown chert; stream tin, haematite, copper, and arsenic were all recorded by Guppy.

Lying east of the Surville Peninsula of San Cristobal is the small island of Santa Ana (Owa raha), whose distinct coral terraces terminate in a peak aptly compared by the Spaniards in 1568 to a castle. Guppy was able to prove that despite the island appearing to be only of coral, it has in reality a dolerite core. The present writer found a limestone whose pale brown colour was attributed to weathering—products derived from basaltic lavas and tuffs. A coarsely crystallized calcite was also found in the coral limestone cliffs of this island.

Slightly to the south-west is the similarly raised island of Santa Catalina (Owa riki), whose summit Guppy found to be a breccia-conglomerate. Rumours of phosphates were disposed of by Sydney University geologists (8), who found the percentage of phosphoric anhydride to be only 1·2 per cent.

North of San Cristobal lies Ugi Island, with a characteristic hump-backed appearance, due to regularly folded mudstones of pteropod and foraminiferal origin. The superficial structure was found by Guppy to consist of hard coral limestone nowhere thicker than 100 feet and not now left at a greater height than 400 feet.

Guppy (1) mentions that in October, 1882, he had a groove cut in the coral cliff in one of the coves of Ugi Island. The height of this line was 6½ feet above half-tide or mean sea-level. The writer in May, 1935, was able to find this datum mark, and found the height at approximately half-tide to be 7½ feet, showing therefore a rise in the island of 1 foot in fifty-three years (9).

Another proof of former elevation is seen in the inclusion of the small adjacent island of Bio within a common 60-fathom line with Ugi (cf. Stirling Island and Mono *supra*). Evidently Bio and Ugi were twin peaks which were submerged and accumulated deep sea deposits and coral before their present elevation to 500 feet. The weathering of Ugi has not proceeded as far as Mono, the volcanic core being nowhere exposed.

Some 12 miles to the east are the Three Sisters, which are entirely of coral-reef formation subsequently elevated in the same manner as Santa Ana. Reed, following Guppy, gives these small islands the height of less than 100 feet, but the lowest is actually 230 feet high.

Rennell or Mungava lies 100 miles south-west of San Cristobal and the same distance south of Guadalcanal; so far neither its exact position nor the coastline have been determined. It is about 45 miles long and is steep-to, with coral cliffs 500 feet in height and only two fair anchorages. It is regarded as the best example extant of an elevated atoll, as its eastern end has a lake filling the former lagoon. This lake, called Tungano, is the largest sheet of freshwater in the South Seas and is 10 miles long. An analysis of the water is given in the middle of a paper (10) on reptiles and amphibians, but does not indicate the hydrogen-ion concentration. The Australian expedition previously mentioned (8) found that the two best samples of limestone contained only 0·59 and 0·11 per cent of tricalcium phosphate. The commercially valuable phosphate from Nauru in the Gilbert and Ellice Islands has a phosphate-content of 80 to 90 per cent.

Lord Howe Atoll (Ontong Java or Liueniua) lies 150 miles north of Isabel and may be regarded as an early phase of what has happened at Rennell. Similarly composed of coral limestone is Sikaiana Atoll or Stewart Island, 125 miles east of Malaita, where, owing to there being no large passage in the reef, it is necessary to land in an outrigger canoe, which is borne right on to the growing edge of the coral.

Separated by open sea of 200 miles extent and of more than 2,000 fathoms depth are the Santa Cruz Islands, none of which are mentioned by Guppy or Reed. Samples from Utupua and Vanikoro Islands were described by Mr. Campbell Smith as porphyritic olivine-basalts, that from Utupua being vesicular.

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The Nomenclature of Some Lower Chalk Ammonites.

By L. F. SPATH.

ONE of the most widely quoted but least common Chalk ammonites is *Ammonites navicularis* Mantell, which has been the subject of a very careful paper by the late G. C. Crick.[1] Judging by the literature, however, this species is still generally misunderstood, and inquiries from correspondents are partly responsible for the present note. There is no doubt that widely different forms have been included in *A. navicularis*, from Sowerby's time (1827) down to the

[1] " On *Ammonites navicularis* Mantell ", *Proc. Malac. Soc.*, xiii, 1919, 154.

present (e.g. Collignon, 1931), and I have on previous occasions [1] separated with new names certain forms wrongly attributed to this species by Sharpe (1857), Guéranger (1867), and de Grossouvre (1912). But although a good deal remains to be done, without figuring typical specimens and without having material for comparison from India, Portugal, and Madagascar, it is not advisable to express opinions on the ammonites figured as *A. navicularis* by yet other authors, e.g. Stoliczka (1865), Choffat (1898), or Boule, Lemoine, and Thévenin (1907).

It must suffice for the present to state that Mantell's type specimen is not unidentifiable, as I thought in 1921,[2] but that, with the additional material available, it can be interpreted and recognized as a different and later species than, for instance, the two forms identified with it by Sharpe. Mantell's species is fairly closely and finely ribbed at diameters below 60–70 mm. (42 ribs at 65 mm. in B.M.N.H., No. 30858 and C. 13911), while very coarse and blunt ribbing sets in at later stages (33 ribs at about 120–130 mm. in holotype, refigured by Crick). The ribs are straight but irregular, long or short, single or bifurcating, and, as in J. de C. Sowerby's *A. navicularis* [3] (with similar but slenderer whorl-shape), there is no trace of tuberculation. Its horizon is the top of the *subglobosus* zone, whereas Sowerby's form probably belongs to the *varians* zone. The latter form is possibly identical with *A. laxicosta* Lamarck (represented by *A. mantelli* d'Orbigny,[4] *non* Sowerby), and the small forms generally ascribed to *A. gentoni* Brongniart, are the inner whorls of examples of this *laxicosta* group. In the true *A. navicularis* apparently not even the closely ribbed innermost whorls are tuberculate on the venter.

The generic and family nomenclature, however, is of more general interest and in the present note I propose to define the different stocks that have given rise to *navicularis*-like species and their allies, and to show how they are interrelated. But first I have to make a correction.

In 1921 I accepted *Mantelliceras* and *Calycoceras* in Hyatt's original meaning, i.e. the former was taken to cover the forms in which there were only two peripheral rows of tubercles, disappearing only "in extreme age", while *Calycoceras* was distinguished by having "a median, ventran line of tubercles during its neanic stage and sometimes later".[5] But I also chose a "type" for *A. navicularis*, finding it impossible satisfactorily to place Mantell's original.

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[1] "On New Ammonites from the English Chalk," Geol. Mag., LXIII, 1926, 82. Also "On the Zones of the Cenomanian and the Uppermost Albian," *Proc. Geol. Assoc.*, xxxvii, 1926, 431.

[2] "On Cretaceous Cephalopoda from Zululand," *Ann. S. Afr. Mus.*, xii, pt. vii, 1921, 315.

[3] *Mineral Conchology*, vi, 1827, 105, pl. 555, fig. 2.

[4] *Pal. Française, Terr. Crét.*, i, 1841, 340, pl. ciii only (badly restored).

[5] "Pseudoceratites of the Cretaceous," *Mon. U.S. Geol. Surv.*, xliv, 1913, 113.

Now Article 25 of the International Rules of Zoological Nomenclature lays it down that the valid name of a species can be only that name under which it was first designated. I take this to imply that if there be an *A. navicularis* at all, it must be the species to which the holotype belongs and not another, like *Mantelliceras cantianum.* It seems to me that this equally applies to *A. fimbriatus* and to the genus *Lytoceras*, in spite of all the ingenious arguments adduced by Buckman.[1] That is to say, *A. fimbriatus* cannot be the type of any other genus than *Lytoceras.*

The genus *Calycoceras* can be considered monotypic, for it was defined in 1903 to apply to a definite form, and if Sharpe's *A. navicularis*, the genotype, subsequently turned out to comprise two distinct species, clearly the one form envisaged by Hyatt must be selected as the lectotype. *Mantelliceras cantianum* thus is valid, but not the selection of 1921. This does away with the objection that *Calycoceras* " cannot now be used " and *Metacalycoceras*, therefore, becomes a synonym of *Calycoceras.* It also follows that the original of Sharpe's fig. 3 (and 5 ?) cannot be referred to *Eucalycoceras*, being the type of *Calycoceras* (*C. subgentoni*). Moreover, *Mantelliceras* is now widely used and the attempt to replace it by *Calycoceras*, which was created first, would not only have led to great confusion but it would obviously be contrary to Hyatt's definition of *Calycoceras.*

It is also advisable to separate from *Eucalycoceras*, and to transfer to *Calycoceras* species like *Acanthoceras newboldi* Kossmat, and others, cited in 1923.[2] This restriction makes *Eucalycoceras* (for the *pentagonum* group, with compressed, and often almost smooth, adult whorls or with the ribbing fine and degenerate) more homogeneous; and *Protacanthoceras* also I would now restrict to the typical *bunburianum-compressum* group (with feebly ornamented, compressed whorls, and the three peripheral rows of tubercles very close together), excluding such forms as *Acanthoceras hippocastanum* (Sowerby), although this is connected with *Protacanthoceras compressum* (Jukes-Browne) by intermediate species like *P. jukesbrownei* Spath. The genera *Euomphaloceras*, *Paracalycoceras*, and *Submantelliceras* are rather distinct, but in the case of flattened species like *Mantelliceras couloni* (d'Orbigny), reference to *Submantelliceras* could be suggested. *A. vicinalis* Stoliczka, if it be really close to " *Mantelliceras* " *saxbyi* (Sharpe) or " *M.*" *couloni* (d'Orbigny), belongs to the same group, and in that case has probably nothing to do with those very compressed forms of *Acanthoceras* that occur in the upper *subglobosus* zone (my " *vicinale* " horizon).

Now these eight genera, with others, have been referred to two families, established on the very principle that prompted Hyatt to separate *Mantelliceras* from *Calycoceras*. But I[1] have already pointed out that Mantelliceratidae cannot be satisfactorily separated from Acanthoceratidae merely because they "never, at any stage, have a row of median, ventral tubercles". I can see no way of connecting *Mantelliceras* with *Douvilleiceras*, not to mention still earlier (Aptian) groups, included by Hyatt in Mantelliceratidae; but I[2] have already shown that Acanthoceratidae and Mantelliceratidae both connect directly with the stock that produced *Stoliczkaia* and the family Lyelliceratidae. It is not only that the feebleness of the median ventral tubercle in young *Mantelliceras* and *Calycoceras* may make them indistinguishable, but that even late *Acanthoceras* derivatives may lose the ventral tubercle and then be classed with Mantelliceratidae, if this family be accepted as first proposed by Hyatt. If used only as a sub-family of Acanthoceratidae, the Mantelliceratidae would include merely the genera *Mantelliceras*, *Submantelliceras*, and probably *Sharpeiceras*, but there is such a perfect series of transitions between *Mantelliceras mantelli*, *M. cantianum*, *M. costatum*, and *M. tuberculatum* to different forms of *Calycoceras* that such separation seems unnecessary.

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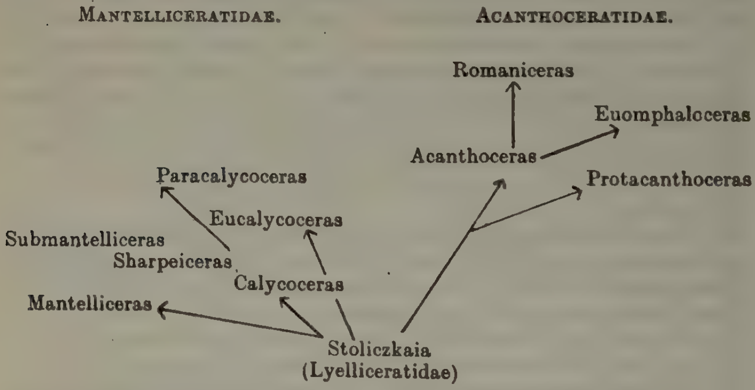
[1] *Yorkshire Type Ammonites,* ii, 1918, xii, xiii.

[2] Spath, " On the Ammonite Horizons of the Gault and Contiguous Deposits," *Summary of Progress, Geol. Surv., 1922* (1923), 144.



On account of this difficulty of separating Mantelliceratids from Acanthoceratids merely on the basis of the presence or absence of a median ventral tubercle, I proposed[3] to include in the former also genera with a median ventral tubercle, so long as they showed a tendency to retain continuous costation across the venter in the adult, such as *Eucalycoceras*, *Paracalycoceras* (and *Calycoceras* itself, as now understood), whereas the Acanthoceratidae I described as showing a tendency to exaggeration of ornamentation on larger whorls (with the exception of the dwarf offshoot *Protacanthoceras* which loses the ribs and lateral tubercles).

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[1] Spath, "On Upper Albian Ammonoidea from Portuguese East Africa, etc.," *Ann. Transvaal Mus.*, xi, pt. 3, 1925, 197.

[2] Spath, "Ammonoidea of the Gault," *Monogr. Palaeont. Soc.*, pt. viii, 1931, 328.

[3] Loc. cit. (*Ann. Transvaal Mus.*), 1925, 197.

The interrelations of the genera discussed are illustrated in the scheme shown on the opposite page.

The Metoicoceratidae, closely associated in Hyatt with the Mantelliceratidae, may be their derivatives, with simplifying suture-lines; but the Vascoceratidae, Mammitidae, and Prionotropidae continue the *Acanthoceras* stock. The first family (Vascoceratidae) includes the genus *Fagesia*, Pervinquière, 1907, to which *A. navicularis* had been wrongly attributed by Grossouvre[1], and later by Crick, although this genus was not mentioned in his posthumous paper.

Outgrowths on Zircon in the Middle Jurassic of Yorkshire.

By F. SMITHSON, Birkbeck College, University of London.

IN view of Mr. J. A. Butterfield's account of outgrowths on zircon in the Millstone Grit of the Pennine region (GEOL. MAG., LXXIII, 1936, 511–16), it may be of interest to record the occurrence of similar grains in the Middle Jurassic sandstones of Yorkshire.

The outgrowths vary in size and occur on zircon of many different types, many of the grains being strikingly similar to those figured by Mr. Butterfield. Frequently the outgrowths protrude from the sides of the grain in the form of small teeth too minute for detailed examination, but agreeing as regards extinction and optical character with the supporting grain. In the larger outgrowths the form $\{111\}$ can be recognized; in one example the angle $111 \wedge 11\bar{1}$ was measured as $94\frac{1}{2}°$, agreeing sufficiently closely with the theoretical value, $95° 40'$. In many cases prism faces are also developed. In a few instances the detrital grain lies with its *c* axis almost perpendicular to the slide, and the outgrowth approaches a square with the edges of the pyramid faces appearing faintly as diagonals. In one such "basal" grain the form $\{101\}$ is recognizable.

In most cases there is little doubt that the outgrowths are authigenic, most of them being too delicate to have survived transport. The only other mineral which shows any evidence of secondary growth is anatase, detrital grains of this mineral having been observed bearing the authigenic mineral in optical continuity.

In the Jurassic sediments zircon of this type is evidently distributed less uniformly than in the Millstone Grit. Out of nearly eight hundred Jurassic samples I have noted zircon with outgrowths in the Lower and Middle Estuarine Series (in 21 samples out of about

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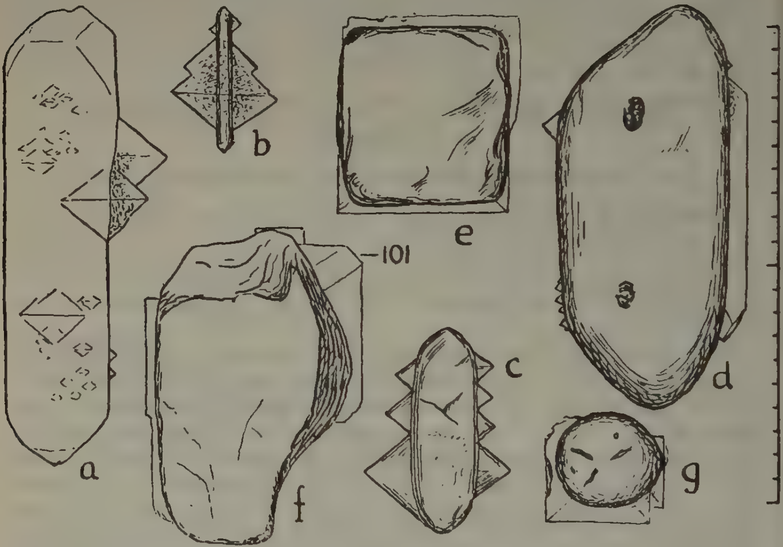
[1] "Le Crétacé de la Loire-Inférieure et de la Vendée," *Bull. Soc. Sci. Nat. Ouest France* (3), ii, 1912, 28.

280), in the Eller Beck Series (in 5 samples out of 22), and in the Upper Estuarine Series (in 13 samples out of 118); but in no other divisions of the Jurassic. Since in a number of residues the outgrowths are small, scarce, and difficult to detect the above figures are probably an under-estimate. In one exceptionally rich sample, a carbonaceous sandstone from the Upper Estuarine Series in the neighbourhood of Hutton-le-Hole, a large proportion of the zircon carries outgrowth. Of the non-opaque grains in the heavy residue a rough count showed: normal zircon 65 per cent, zircon with outgrowths 25 per cent, rutile, etc., 10 per cent.



Text-fig. 1.

a.–c.—Zircon from the Lower Estuarine Series. a.: Numerous outgrowths on almost unworn prism as seen when focusing on upper surface. b, c: Grains with large outgrowths.
d.-g.—Zircon from the Upper Estuarine Series. d.: Outgrowth showing prism face. e, f, g.: "Basal" grains. Note the {101} face in f.
Each scale division represents one-hundredth of a millimetre.

In parts of North-East Yorkshire the Estuarine Series contains a considerable amount of garnet, together with staurolite. So far as I have observed, zircon with outgrowths does not occur in such residues, but is confined to the region (approximately defined by Sheets 43 and 44 of the 1 in. Geological Survey Map), where the assemblages are extremely impoverished, i.e. contain neither garnet nor staurolite, but consist chiefly of ilmenite, leucoxene, zircon, and rutile, frequently with much authigenic anatase and/or brookite.

Strange to say, the unstable mineral apatite is occasionally present in these impoverished assemblages.

Often these zircons are found in only one of a series of samples collected at one place. In the stream course of the Eller Beck near Goathland, however, they are more persistent. Seven samples collected between the Dogger and the Eller Beck Bed all yielded zircon with outgrowths: in the Eller Beck Bed, out of eight samples it was found in the lowest and the two highest: and it occurred again in the sandstone above the Eller Beck Bed. Other occurrences are scattered widely in an east–west belt extending from the Scarborough–Robin Hood's Bay coast over the moorlands, but in the extreme north of the Jurassic area and in the belt extending along the line of the Hambleton and Howardian Hills no examples have yet been observed.

Until we know of other occurrences of outgrowths on zircon it may be unwise to generalize, but one feature common to the occurrences recorded by Mr. Butterfield and those recorded here may be of some significance—all the deposits in question are either deltaic or closely associated with deltaic conditions.

REVIEWS.

CONGRÈS INTERNATIONALE DES MINES, DE LA MÉTALLURGIE, ET DE LA GÉOLOGIE APPLIQUÉE, 7th Session, Paris, October, 1935, Section de Géologie Appliquée. 2 vols., 4to, pp. 1088. Rue de Bourgogne, Paris VII^e.

IT is difficult to know how the bibliographical title of this book should be quoted, as the title-page contains a great deal more than is set out above, and none of it is strictly a title; however this short summary is probably sufficient to be recognizable by a bookseller. It appears to be a joint publication of several institutions and societies with the patronage of the French Government.

In fact the two volumes contain an enormous number of monographs on economic geology presented in the form of papers at the Congress held in Paris in 1935. Their number is so great that it is impossible even to enumerate them: all that can be done is give a list of the headings under which they are classified, as follows:—Ore-deposits of magmatic origin; ore-deposits of sedimentary origin; petroleum; geology applied to public works; geology applied to agriculture; hydrology; geophysics; teaching and research institutions; and as an appendix, studies in applied geology in the Portuguese colony of Mozambique.

The scope is world-wide, the list of authors includes many famous names, and it is evident that specialists in almost any branch of economic geology will find here much of value.

R. H. R.

THE PETROLOGY OF THE IGNEOUS ROCKS. By the late F. H. HATCH and A. K. WELLS. Ninth edition. pp. xx + 368, with 154 text-figures. London: George Allen and Unwin, Ltd., 1937. Price 15*s*.

THE most important change in this edition is in connection with the definition and nomenclature of what are commonly called the hypabyssal rocks. The separation of minor intrusions and surface flows into petrographical classes is no longer based on manner of occurrence, but solely on grain-size, following a suggestion put forward by a committee of the British Association in this Magazine in July last. As this scheme was admittedly tentative and a basis for discussion, it seems somewhat premature to adopt it in an elementary textbook, since it involves the abandonment of such well-known names as quartz-porphyry and dolerite. The author himself admits candidly that the last-named at any rate will die hard: its substitute, microgabbro, is not attractive.

Since there has been no public discussion of this scheme, it may be well to take this opportunity of mentioning one point which seems important, namely, that the limit of grain-size adopted by the Committee to demarcate the coarse and intermediate types is much too low. Taking for example the case of a non-porphyritic granitic rock, it is proposed that all rocks in which the maximum diameter of equi-dimensional grains exceeds half a millimetre shall be regarded as coarse. Let us take some figures: the writer's microscope with a 1 in. objective and an average eyepiece gives a field of exactly 3 mm. diameter; hence six grains of half a millimetre can be seen in a row in any direction. This may seem coarse to a laboratory petrologist, but few field-workers would regard a rock with an average grain size of one or even two millimetres as coarse. The report of the Committee is admittedly founded on the study of "111 slides", and this seems to be the explanation of the difficulty: that insufficient attention was paid to the naked-eye or pocket-lens aspect of petrography. Taking, again, the lower limit of the intermediate class, a grain of 0·05 mm. diameter is invisible to any ordinary eyesight without assistance, as the writer well knows from study of sand grains. It would seem that the figures chosen by the Committee should be multiplied several times.

Briefly, then, it is suggested that the names now in use for the intermediate rocks should be replaced by microgranite, microgabbro, and so on, while retaining the ordinary plutonic and volcanic names for coarser and finer groups irrespective of modes of occurrence. Thus a basalt dyke becomes quite legitimate. It must be admitted that this system has many advantages, if the limits had been differently selected, with more regard for field-workers.

It would have been well if the author had given a clear statement earlier in the book of what the size-limits adopted really are. A careful search shows that the first actual definition of the upper limit comes in rather casually on p. 155, in the description of microgranites, although this system is stated in the preface to be an essential feature of the classification adopted in the book, while the definition of the lower size-limit is postponed to p. 162. This makes things rather difficult for elementary students, who cannot be supposed to read the GEOLOGICAL MAGAZINE.

But to pass from this general discussion to a review of the book itself. It is obvious from what has already been said that a good deal of it has had to be re-written, and owing to the death of Dr. Hatch since the publication of the eighth edition this has had to be undertaken by Dr. Wells alone. The result is as readable as an elementary text-book can be. In another question of nomenclature, exception may perhaps be taken to the use of the terms orthosyenite, orthogabbro, and so on for what are regarded as the typical members of each group, as there is a risk of confusion with the prefix "ortho-" in metamorphism. In a future edition tachylite should be altered to tachylyte, and the reviewer ventures to suggest, with all due respect both to the late Dr. Prior and the rules of priority in general, that kenyite would be an improvement on kenyte: this is, however, hardly a matter for a textbook, but for the higher powers in petrology, whoever they may be.

The chapter on the consolidation of magmas gives an excellent summary of modern work in the light of physical chemistry, with due regard to Dr. Bowen's continuous and discontinuous reaction series and so on, but perhaps wisely, little is said as to how magmas have come into existence. They are just assumed, so to speak, and their crystallization is duly discussed.

In conclusion it may be said that Dr. Wells has carried out his work of revision remarkably well. Printer's errors and errors of fact are remarkably rare. In several places Shap is said to be in Cumberland, and one of the occurrences given for kaolinite (Amlwch, Anglesey) is the type locality for dickite. The reproduction of some of the figures, especially the microphotographs of rock-sections, leaves a good deal to be desired, but these are minor blemishes, and the appearance of this new edition is to be heartily welcomed as a contribution to the understanding by elementary students of a difficult subject.

R. H. R.

THE QUATERNARY ICE AGE. By W. B. WRIGHT. Second Edition. pp. xxv + 478, with xxiii plates and 155 text-figures. Macmillan and Co., 1937. Price 25*s*.

At first sight this seems to be no more than a second edition of a book that has been in constant use for nearly twenty-five years: plates and many of the figures are the same, and most of the chapter headings. But four new chapters are added, and at intervals lists of references, with a 25 per cent increase of letterpress. Three of the new chapters are devoted to the elaboration of field work in this country, the fourth to glacial retreat, varves, De Geer's work, periodicity, and time scale.

Close inspection shows that a great deal of revision has been done to bring the book up to date on a conservative plan. Some controversial questions have to be faced in following the plan of the earlier edition, but the policy enables others to be avoided, and the book is already as large as can conveniently go into one cover.

It is too much to hope that Wright's chapters on this country (e.g. IV and V) could please everyone, but in these and others the reviewer considers that a very fair *via media* has been followed: local experts will no doubt find minor faults, and archaeology occupies a secondary place. For Chapter I (Glaciers and Ice-Sheets) the text and bibliography might well have contained more and newer material. As Sollas, in *Ancient Hunters* (by the same publishers) dwelt on France and Spain, so Wright emphasizes Scandinavia, the Baltic, Central Europe, and the Alps: a happy combination. In the restatement of his Isokinetic Theory Wright also combines isostasy and eustatism in a way that may shock protagonists of each, but the hypothesis establishes a flexible line of thought that is more than welcome.

In the last chapter, having correlated glacials and interglacials in various directions, Wright refuses to be drawn into the application of the East Alpine terminology outside the Alps: it was high time that the geological standpoint was bluntly defined in a textbook that is widely used. The author is to be congratulated on getting so much information authoritatively and readably put together: the book is indispensable to any geological or general science library.

K. S. S.

CORRESPONDENCE.

THE COELACANTH GENUS *GRAPHIURUS* KNER.

Sir,—Our attention has been drawn to the fact that the generic name *Graphiurus* (*G. callopterus* R. Kner, 1866, Sitzungsb. k. k. Akad. Wiss. Wien, math.-naturw. Cl., liii, pt. i, 155), applied to a Coelacanth fish from the Upper Keuper of Carinthia, has long been preoccupied by that of the African dormouse, *Graphiurus* Cuvier (1829, in Geffroy & Cuvier, *Hist. nat. Mam.*, iii (livr. 60), 2); we propose to distinguish the fossil as *Graphiurichthys*.

Errol I. White.
J. A. Moy-Thomas.

Dept. of Geology,
Brit. Mus. (Nat. Hist.).
12th April, 1937.

AUGITE-BIOTITE-DIORITE.

SIR,—Miss Reynolds's reply in the December number of GEOL. MAG. to my letter in the October number does no more than prove my contention that it is futile to quarrel about the application of rock names until we are agreed about the meanings of these names. It is quite clear that gabbro-diorite means one thing to Professor Bailey and me, and another to Miss Reynolds. She now says augite-biotite-diorite " certainly is not diorite ", which leaves me wondering what her definition of diorite may be, and that it " obviously is not gabbro-diorite ". If she means that it is not gabbro-diorite in Niggli's classification then, of course, I agree; but in her former letter she referred to Tröger as her authority. The fact is that these points, which seem so certain and so obvious to Miss Reynolds, are no more than personal impressions, and they can never be anything more until we all agree to use the same names in the same sense. That is the point I tried to make in my previous letter. " The beginning of knowledge is the investigation of terms."

S. J. SHAND.

GEOLOGY DEPARTMENT,
UNIVERSITY OF STELLENBOSCH.
30th January, 1937.

AUGITE-BIOTITE-DIORITE.

SIR,—May yet a third member of the British Association Committee on Petrographic Classification and Nomenclature venture to express an opinion on the use of the name " augite-biotite-diorite " ?

The only principle involved is whether normal rock names should be applied to rocks demonstrably of hybrid origin. In so far as modern tendencies are concerned, the opinion is growing that many, perhaps most, syenites, diorites, and monzonites (syenodiorites) are of hybrid origin, and in the circumstances we cannot do other than use well-established names for rocks having certain mineralogical and chemical characters, regardless of their mode of origin. That being so, there are two names from which a choice must be made: is the rock a diorite or a gabbro? To this simple question it is impossible to give a simple, unqualified answer which will please all geologists, because it is a lamentable fact that the two may be distinguished by at least three different criteria: silica percentage, colour index, and kind of plagioclase. In the circumstances it is essential that petrologists should clearly indicate whose definition of the name finally chosen is being adopted, by placing the author's name in brackets after the rock name. This would prevent the minor shocks administered by suddenly meeting a common name used in an unfamiliar sense. Probably the most popular means of distinction between diorite and gabbro is silica percentage. On this basis it was incorrect to call the rock a diorite, as its silica is 49 per cent, which places it well within the limits of the basic group. From this point of view the rock is undoubtedly a gabbro; and consistent with this naming are the facts that it contains much coloured mineral, the chief, judging from the published figure, being clino-pyroxene, though biotite is recorded as dominant in the mode. The rock differs from normal (calc-alkaline) gabbro in two respects: a high content of biotite, and the more strongly sodic character of the plagioclase. Both facts should be conveyed in the name chosen by using a suitable qualifier. I suggest that "hybrid sodi-potassic gabbro" is the correct naming from my point of view; and there is little difference between this and the name arrived at by following Shand's scheme, according to which it would be "biotite-rich soda-gabbro (Shand)". By the way, there is no incongruity in this naming, which is eminently reasonable and self-explanatory.

Two minor points in this discussion will bear further examination. What exactly is meant by Miss Reynolds's statement (GEOL. MAG., 1936, p. 560) that augite-biotite-diorite is certainly not diorite? To say that augite-biotite-diorite is not diorite in its bare essentials is to admit that a wrong name has been used: for the same principles apply as in naming fossils, flowers, or any other natural objects. It is like saying that *Didymograptus murchisoni* var. *geminus* is not *Didymograptus*. The "augite-biotite-" part of the name plays the same role as the trivial part of the fossil name: diorite is the genus, determined on broad characters; augite-biotite-diorite is a species, so named on its trivial characters.

Finally this discussion has raised the question of the meaning to be attached to hyphenated words. Apparently three different meanings have been attached to different times to "gabbro-diorite": this is sufficient, in my mind, to disqualify the name from use altogether. In a classification based rigidly on silica percentage there is only one gabbro-diorite, the rock, not yet discovered, which contains exactly 45·00 per cent of silica. If it contains 44·99, it is a gabbro, if 45·01 it is a diorite.

A. K. WELLS.

KING'S COLLEGE, LONDON,
18th January, 1937.

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ORIGINAL ARTICLES.

The Cairnsmore of Fleet Granite and its Metamorphic Aureole.

By Charles Irving Gardiner and Sidney Hugh Reynolds.

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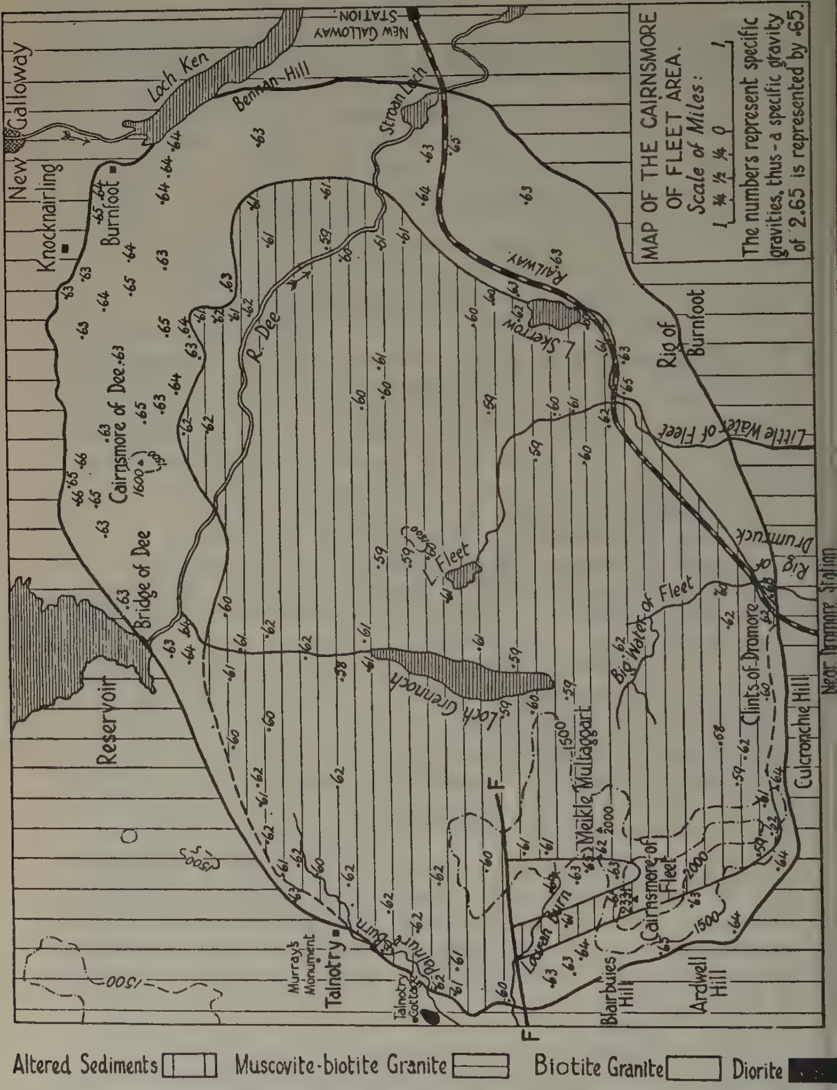
I. Introduction.

THE Cairnsmore of Fleet granite is the second in point of size of the four plutonic masses which penetrate the Lower Palaeozoic rocks of the Southern Uplands of Scotland, being exceeded in area only by that of the Criffel. Its outline is roughly oval and it measures 11 miles by 7 miles, the long axis trending N.E.–S.W., exactly parallel to the strike of the rocks of the Southern Uplands.

While the Loch Doon granite mass, described by us in 1932, is intrusive in Ordovician sediments, the rocks surrounding the Cairnsmore of Fleet mass are in the main Silurian (Llandovery–Tarannon), though they include some black slates and cherts of Ordovician age. The district comes just at the junction of four of the new 1 in. Geological Survey maps, being included in sheets 4, 5, 8, and 9.

The plutonic mass extends from near New Galloway in the north-east to within 4 miles of Newton Stewart in the south-west. It differs from the Loch Doon mass in its relative accessibility, being nowhere shut off by lofty hills. The road from Newton Stewart to New Galloway follows close along the northern and north-western



TEXT-FIG. 1.—Geological Map of the Cairnsmore of Fleet Area.

boundary, and the railway between New Galloway station and Newton Stewart traverses the south-eastern part of the mass.

The highest points in the granite are near the western boundary, the Cairnsmore of Fleet itself reaching 2,328 feet and the neighbouring Meikle Multaggart 2,000 feet. The Cairnsmore of Dee, the highest point in the northern part of the area, is 1,600 feet high. The remainder of the granite does not often rise above 1,000 feet.

The granite extends to the shore of Loch Ken in the north-east, and encloses several considerable lochs, though not so many as the Loch Doon " granite " mass. The largest is Loch Grennoch, which is nearly 2 miles long, though only one-third of a mile wide at its widest. The River Dee (Black Water of Dee) traverses the north-eastern part of the mass and receives the outflow from Loch Grennoch. But a considerable part of the drainage is southwards by the tributaries of the Water of Fleet. The country is practically uninhabited and save for the track leading to Loch Grennoch shooting-lodge the interior contains nothing that can be termed a road. The road between the Bridge of Dee and Talnotry lies just within the granite area.

The area has received a little more attention from geologists than that of Loch Doon. The earliest reference to it is in a paper by Sir James Hall (1818), who showed clearly the intrusive nature of the granite and noted that its heat had converted the " killas " into " gneiss or mica-slate ". He also observed that near the Bridge of Dee on the north-western boundary the strata dip off the granite, whilst south-west of Loch Ken the granite junction cuts across the strata nearly at right angles.

In addition to Teall's account in the Geological Survey Memoir on the Silurian rocks of Scotland (1889), two descriptions have been published of the metamorphism in the neighbourhood of New Galloway, that by Allport and Bonney (1899) and that by Miss M. I. Gardiner (1890). The former paper mainly consists of a description by Bonney of rock specimens collected by Allport. That by Miss Gardiner is referred to more fully in the sequel.

The most recent reference to the New Galloway rocks is in a paper by Tilley (1926), in which a partial analysis of garnet from the contact rock at Knocknairling is given and stress is laid on its richness in manganese (MnO 14·88 per cent).

The metalliferous diorite near Talnotry was alluded to by G. V. Wilson (1921) and O. T. Jones (1924) and was fully described by Gregory (1927). The accounts by the present writers of the Loch Doon " granite " (1932) and by W. A. Deer (1935) of the Cairnsmore of Carsphairn igneous complex bear upon the area now being discussed.

II. The Plutonic Rocks

As stated by Teall, the Cairnsmore of Fleet mass is decidedly more acid in character than any of the other three major intrusions of the Southern Uplands.

The rocks are of two closely related types only—

(1) a biotite-granite (average Sp.G. 2·64).
(2) a biotite-muscovite-granite (average Sp.G. 2·61).

As is shown in the map, all the central area surrounding Lochs Grennoch and Fleet consists of biotite-muscovite-granite, while the biotite-granite prevails along the north-east and south-west boundaries. The distribution of rock-types is analogous to that in the Loch Doon and Carsphairn masses in the fact that the more basic rock lies external to the more acid.

The predominance of biotite-muscovite-granite over biotite-granite was not recognized by Teall, the specimens at his disposal leading him to state (*op. cit.* p. 622) that biotite-granite is the dominant rock. The boundary line drawn on the map between the two varieties, conforms fairly regularly to the outline of the whole plutonic mass. The marginal strip of biotite-granite varies, however, in width, being widest in the north-eastern and eastern part of the area. In the western part between Louran and Palnure burns we have no evidence of a marginal strip of biotite-granite and the same remark applies to the margin for about 2 miles westward from the Big Water ot Fleet. In each case, however, better exposures might disclose its presence. Just north of the Cairnsmore of Fleet an area of biotite-granite tapering southwards, and apparently cut off by a fault on the north, is separated from the main marginal development of biotite-granite by a strip of biotite-muscovite-granite.

The Petrography of the Granite.

The granite, which shows little variation, was described in considerable detail by Teall, to whose account we have little to add. In the biotite-granite the chief constituents are biotite, quartz, and microcline with oligoclase and orthoclase. Of the three felspars microcline is the most abundant and orthoclase is sometimes less abundant than oligoclase. A vermicular (myrmekitic) intergrowth of quartz and felspar is not infrequent, especially in rocks rich in biotite. A core of corroded felspar sometimes recognizable as oligoclase is frequently enclosed in a secondary growth of the same mineral. The biotite is often much chloritized. A little hornblende is occasionally present and in a few cases pyrite, while apatite and zircon are common as accessory minerals. As in the Loch Doon mass, zircons with pleochroic halos are very common in the biotite. As Teall points out, save for the presence of muscovite in the central mass of granite, the two varieties are practically identical.

The two analyses by Mr. E. G. Radley quoted below, one of muscovite-biotite-granite [1027][1] and one of biotite-granite [1072], show no great difference. The percentages of silica and soda are greater in 1027, those of potash and iron ores in 1072.

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[1] Throughout the paper the numbers in square brackets refer to field localities.

	muscovite-biotite-granite. 1027	*biotite-granite.* 1072
SiO_2	73·26	71·18
TiO_2	·30	·47
Al_2O_3	14·29	14·78
Fe_2O_3	·98	1·20
FeO	·97	1·35
MnO	·04	·06
(CoNi)O	not found	trace
CaO	1·14	1·58
MgO	·69	·82
K_2O	4·04	4·82
Na_2O	3·48	3·10
Li_2O	trace	not found
H_2O at 105° C.	·04	·11
H_2O above 105° C.	·42	·15
P_2O_5.	·25	·38
CO_2.	·45	·29
	100·35	100·29

The rocks show very little tendency to a porphyritic structure, in this respect differing from those forming the innermost parts of the Loch Doon and Carsphairn plutonic masses.

The specific gravities of 132 specimens of biotite-muscovite-granite varied from 2·58 to 2·62, the average as already stated being 2·61, those of 88 specimens of biotite-granite from 2·63 to 2·67, the average being 2·64.

In the neighbourhood of the Clatteringshaws reservoir, recently constructed to the north of the Bridge of Dee, the granite becomes distinctly gneissic, as is well seen in the new quarry. We have not found any other occurrence of a gneissic structure.

IV. APOPHYSES OF THE GRANITE.

Aplite.—Aplite veins are very abundant in relation to the Cairnsmore of Fleet mass, far more so than in the case of the Loch Doon mass.

They occur at numerous points around the margin penetrating both the granite and the surrounding metamorphic rocks, but are especially plentiful when the granite is transgressive, e.g. near the south-western boundary on Blairbuies Hill and near the north-eastern boundary on Bennan Hill and close to Burnfoot near New Galloway. Aplites are also frequently found well within the granite mass as on the Cairnsmore of Dee and on the western side of Loch Grennoch. They are white or pinkish rocks varying considerably in coarseness of grain and are of quite the normal type in general appearance. They differ from the aplites of Loch Doon in the fact that muscovite is almost invariably present and, in the majority of cases, garnet. Microcline is probably the most abundant felspar, especially in the coarser grained rocks ; orthoclase and, more rarely, albite, also occur. Biotite and tourmaline are sometimes present but less often than in the case of the Loch Doon aplites. In one case, a little pale green amphibole was found.

Pegmatite.—Pegmatite veins are fairly frequent in the marginal part of the granite and adjacent rocks, particularly in the New Galloway area. Good examples are seen at Burnfoot, in a quarry by Loch Ken, 2½ miles south of New Galloway, and at Bennan Hill. Muscovite commonly accompanies the orthoclase and quartz, and sometimes, as at Burnfoot, garnets are plentiful. The Burnfoot rock is exceptional in having yielded a large crystal of cordierite, which through the kindness of Professor A. Hutchinson, was determined in the Mineralogical Laboratory at Cambridge. Typical graphic granite occurs at Blairbuies Hill.

IV. RELATION OF THE PLUTONIC MASS TO THE SURROUNDING SEDIMENTARY ROCKS.

Along the north-western boundary the sediments dip north-west, i.e. off the granite, which near the Murray monument, Talnotry, is clearly seen to pass below them. Similarly along the south-eastern boundary the rocks dip south-east off the granite. These relations suggest that the intrusion is laccolithic in character. A similar conclusion was reached regarding the Loch Doon and Carsphairn masses. On the other hand, at the north-eastern and south-western ends of the granite the relation is transgressive, the sediments for example at Knocknairling Hill in the north-east and at Ardwell Hill in the south-west striking directly at the granite.

Inclusions of the country rock are far less common than in the Loch Doon area and are especially rare where the granite boundary runs parallel to the strike. Only at one locality, Bennan Hill, south of New Galloway, where the relation of the granite to the sedimentary rocks is transgressive, have we found a contact zone in any way comparable in complexity with that in parts of the Loch Doon area.

V. THE DIORITIC ROCKS.

(*a*) *The Talnotry "Diorite".*

The Cairnsmore of Fleet granite contrasts with that of Loch Doon in the almost complete absence of considerable intrusions of a relatively basic character, at a short distance external to the margin of the granite mass. There is, however, one locality where such an intrusion occurs, namely, near Talnotry, close to the western boundary of the mass. Here there are several exposures of diorite, a major one forming a roughly oval patch about 250 yards long from north-east to south-west and three smaller ones. The larger patch lies north of the Palnure Burn, between it and Talnotry Cottage, while two of the smaller patches lie on the south side of the burn. The third of the smaller intrusions occurs north of Drumlawhinnie Loch, about a mile south-west of Talnotry Cottage. These rocks have a high specific gravity, 3·03 having been found in the case of a specimen taken from the more southerly of the two small intrusions south of Palnure Burn.

All these rocks, with the exception of the one from Drumlawhinnie Loch, consist mainly of pale hornblende, which is often idiomorphic, with subordinate plagioclase and a little quartz and orthoclase. Apatite and sphene are abundant in some sections. At its southern end the major exposure contains abundant nickel- and cobalt-bearing pyrrhotite. Allusion has already been made to the descriptions of this ore-bearing rock. Originally, perhaps, the Talnotry rock was a normal diorite, but it shows features which suggest comparison with some of the hornblende hybrids of the outer basic group of Carsphairn, especially in the fact that reconstruction of the hornblende aggregates leads to the marginal development of brown hornblende and biotite. A similar change was described from the Loch Doon area (*Quart. Journ. Geol. Soc.*, lxxviii, 1932, pl. I, 2). Such replacement is attributed in the case of the Carsphairn rock to hybridization, but in the case of the Talnotry diorite, the field relations of which appear to have little in common with those of the Carsphairn rocks in question, the change in the hornblende may be due to contact metamorphism, of which there is good evidence. Gregory alludes to the alteration shown by part of the diorite, and states that Dr. G. W. Tyrrell attributes both it and the deposition of the ores to hydrothermal action. While agreeing with these authorities in considering that the ore was introduced rather than magmatic, we differ in attributing the alteration to contact metamorphism by the neighbouring granite.

Two analyses[1] of the Talnotry diorite were made by Mr. E. G. Radley, one (Lab: 702) from a spot near the northern end of the chief exposure, the other (Lab: 703) from the south-central part of the same exposure. Only certain of the results are quoted below:—

	Lab: 702	Lab: 703
SiO_2 .	51·96	65·19
Al_2O_3 .	11·93	16·31
FeO .	8·43	3·44
CaO .	7·28	3·41
MgO .	11·06	1·50

The marked variation in different parts of the mass is clearly brought out by these figures. Neither of the rocks analysed contained any nickel or cobalt, which are apparently very local and confined to the southern end of the intrusion.

Sections show that both the small intrusions south of the Palnure Burn consist mainly of hornblende with some much weathered felspar and a little magnetite and apatite. The hornblende, which tends to be idiomorphic, is predominantly pale and actinolitic. This seems to be the original state of the mineral, but there has been much replacement by brown hornblende, which is, in its turn, partly replaced by biotite.

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[1] *Summary of Progress Geol. Surv. for 1923* (1924), p. 134.

The Drumlawhinnie rock is different from the others. It contains less hornblende and more felspar. A considerable amount of original quartz and some chloritized biotite are present.

(b) *The Airlie Hill Dyke.*

A dyke [509], in some respects similar to parts of the Talnotry diorite, occurs on the slopes of Airlie Hill, 1¼ miles to the west of New Galloway. It consists of pale augite, often idiomorphic, and more or less replaced, partly by actinolitic amphibole, partly by brown hornblende, while a subsequent partial replacement by biotite has also take place. Large, somewhat turbid and ill-defined patches of apatite are present in the section examined, with a few large plagioclase crystals and a conspicuous patch of micropegmatite. Mr. Radley found 58·47 per cent of silica in this rock. Dr. H. H. Thomas considered the rock to be of a mixed character and that the apatite and large plagioclase crystals were derived from a gabbroid magma. Similarity to the Talnotry diorite is seen (*a*) as regards the ferromagnesian minerals, (*b*) in the presence of apatite and (*c*) of micropegmatite, and (*d*) in the fact that there are indications of metamorphism. The intrusion, like that of Talnotry, was probably pre-granitic.

VI. THE MINOR INTRUSIVE ROCKS.

The Cairnsmore of Fleet mass contrasts with that of Loch Doon in the relative scarcity of minor intrusions in the rocks immediately surrounding it. This fact is clear merely from inspection of the 1 in. Survey maps, though there are numerous dykes in relation to the Loch Doon granite which are not shown in the map of that area. The scarcity of "felsite" dykes, of which there are probably several hundred in the Loch Doon area, and of lamprophyres is specially noteworthy.

"*Felsite.*"—Allusion has already been made to the scarcity of fine-grained acid and intermediate rocks to which the field term felsite is conveniently applied. We have found none cutting the granite and comparatively few in the sediments in its immediate neighbourhood. We have had sections cut of very few of these rocks, and the only one to which it seems worth while to allude is a soda-felsite [1178] or keratophyre penetrating the sediments near the south-eastern corner of Stroan Loch. This rock shows features suggesting alteration and that it is a pre-granitic dyke.

Monchiquite.—The most interesting dyke [74] is one which occurs on the Rig of Drumruck, near the junction of the granite with the altered rocks, and south-east of the point where the railway crosses the Big Water of Fleet. The rock, which is very fresh, is a monchiquite, chiefly consisting of fresh, idiomorphic olivine and pale brown augite partly replaced by rich brown hornblende. Numerous small crystals of titano-magnetite are present and a limited amount of plagioclase. The rock is quite unlike any other that we have found either in the Cairnsmore of Fleet or in the Loch Doon areas, and is probably a post-Caledonian intrusion. Its silica percentage is 42·16.

Somewhat similar rocks are described from Coll[1] and the Ross of Mull,[2] but the rocks which the dyke from the Rig of Drumruck most closely resemble certainly seem to be the monchiquites of the Orkneys.[3] We are indebted to the late Dr. H. H. Thomas for drawing our attention to this fact.

VII. THE METAMORPHIC ROCKS.

Conspicuous metamorphism of the rocks surrounding the granite is seen at several places, the chief being Knocknairling Hill west of New Galloway, Bennan Hill south of the same town, in the railway cutting at Dromore, and at Culcronchie Hill west of Dromore. The rocks in contact with the granite are almost entirely Silurian grits and flags, the Ordovician black slates and cherts which in the Loch Doon area show remarkable metamorphism, only rarely occurring near the granite mass.

As in the Loch Doon area quartz-biotite-schist and hornfels are the commonest rocks, andalusite-schist and cordierite-hornfels coming next in abundance. Andalusite-schist is more plentiful than in the Loch Doon area and rocks with andalusite conspicuous on the weathered surface are seen at many places, such as Culcronchie Hill, Dromore railway cutting, Bennan Hill, and Knocknairling Hill. Cordierite-hornfels and chiastolite-slate, on the other hand, are less plentiful than in the Loch Doon area. Garnets are often abundant, and the hornfels occasionally contains sphene. Other rock types represented are graphite-schist [66], from the Rig of Burnfoot, actinolite-schist [106], from Blairbuies Hill, chlorite-schist from the southern end of the Stroan Loch, and corundum-mica-schist [470], from Bennan Hill.

(a) *Knocknairling Hill.*

Much the most remarkable metamorphism in relation to the whole granite mass is that of Knocknairling Hill, about 2 miles west of New Galloway. A full description of the interesting exposures seen here is given by Miss M. I. Gardiner (1890) and in the Survey Memoir. We have few new facts from this area to record, but it seems desirable, for the sake of completeness, to summarize briefly those already known. A series of fine-grained grits, flags, and black slates, striking directly at the granite, shows progressive metamorphism. The argillaceous rocks pass into andalusite-mica-schist, large, highly polarizing crystals of andalusite being present in some sections. The gritty beds give rise to coarse-grained quartz-mica-schist with sillimanite and sometimes a little felspar. Biotite predominates in the mica-schist, but muscovite is also plentiful. Lenticles of garnet-quartz-rock, sometimes 5 or 6 inches long, probably represent calcareous concretions in the original rock. The sillimanite often forms radiating masses of needles.

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[1] *Geology of Ardnamurchan, North-West Mull and Coll*, 1930, 359.

[2] *Geology of Staffa, Iona, and Western Mull*, 1925, 82.

[3] *Geology of the Orkneys*, 1935, 180.

(b) *The Western Shore of Loch Ken, especially Bennan Hill.*

The fact that metamorphism here was first recognized by Sir James Hall (1815) and was described by Allport and Bonney (1889) has already been alluded to. The latter authors found hornblende, tourmaline, garnet, and epidote in the altered rocks.

In the northern part of Bennan Hill, the junction between granite and altered rocks is very complex, many tongues of granite extending into the sedimentary rocks, which include black slate as well as the usual grit. The altered rocks include a variety of types, the commonest, as elsewhere, being biotite-hornfels, but muscovite is exceptionally abundant and sometimes occurs to the exclusion of biotite.

A rock [470] from the south end of the hill is a cordierite-mica-schist with biotite, muscovite which includes wisps of sillimanite, and andalusite in crystals which may reach a length of two-thirds of an inch and are conspicuous on the weathered surface. Corundum, sometimes showing the dark blue colour of sapphire, is also present, each patch being seen in section to be surrounded by a mass of muscovite.

(c) *Dromore.*

In the railway-cutting granite with aplitic apophyses is seen penetrating the altered rocks, which consist chiefly of compact fine-grained biotite-cordierite-hornfels, but include also biotite-andalusite-schist, the andalusite being as usual conspicuous on the weathered surface.

(d) *The South-Western Boundary.*

Excellent examples of metamorphism are seen on Culcronchie and Blairbuies Hills. On the former andalusite- and actinolite-schist were collected and on the latter tremolite-schist.

VIII. Summary and Conclusion.

The principle facts regarding the Cairnsmore of Fleet granite mass are as stated below:—

1. The plutonic rocks show little variation and are all granite. The major and central part of the mass consists of biotite-muscovite-granite, while biotite-granite occupies most of the marginal tract.

We consider that these rocks were the products of successive injections separated by no great interval of time, the biotite-granite being the earlier.

In view of the similarity of the two types, which differ only in the lower specific gravity and the higher silica percentage of the muscovite-granite, transitional types can scarcely be expected to occur and were not found.

2. Minor intrusions are relatively scanty, not only in the granite itself, but also in the immediately surrounding rocks, Such as occur are all of the nature of small dykes with the exception of the diorite of Talnotry. The clear signs of metamorphism, which this rock shows, point to its being a pre-granitic intrusion.

The most interesting dyke, a monchiquite, is unlike any other dyke found in the Cairnsmore of Fleet or Loch Doon areas, and is probably a post-granitic intrusion.

3. The metamorphosed sediments surrounding the plutonic mass are mostly quartz-biotite-hornfels, cordierite being less plentiful than in the rocks surrounding the Loch Doon mass. The metamorphism is sometimes very conspicuous.

The trend of the plutonic mass is Caledonian and parallel to that of the strata into which it is intruded. While at the north-eastern and south-western ends of the mass the granite cuts across the strike of the sediments, along the north-western and south-eastern margins these dip off the granite, which may be regarded as an intrusion essentially laccolithic in character. Very little evidence of faulting was found.

We are greatly indebted to Dr. A. Harker and the late Dr. H. H. Thomas for help in the examination of some of our sections.

A large part of the expense incurred, especially in rock cutting and rock analysis, has been defrayed by grants from the University of Bristol Colston Society.

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Anthophyllite-Cordierite-Granulites of the Lizard.

By C. E. Tilley.

I.

THE region of Trelease Mill and Polkernogo, west of St. Keverne, forms one of the type outcrops of the Old Lizard Head Series north of the main Lizard gabbro. This small rather poorly exposed tract is distinguished not only because it has yielded the only recorded cordierite-bearing rocks among the Lizard schists but more particularly on account of the occurrence of the rarer rock types carrying anthophyllite together with abundant cordierite.

A description of these interesting rocks with their field relations has been given by Sir John Flett in the *Survey Memoir* [1][1] (pp. 37, 39–40). Field exposures leave much to be desired but fresh material can be got at points in the vicinity of the stream at Trelease. Rocks of undoubted sedimentary origin, including muscovite-biotite-schists with cordierite, occur on the western bank of the stream close to the Foot Bridge. Flett has noted cordierite-granulites on the road leading up to the slope east of the Mill.

These latter rocks are rich in cordierite, biotite, quartz and oligoclase or andesine. They are distinguished by the presence of fine felts of sillimanite which appear for the most part as fringes to the grains of colourless minerals. The identity of this mineral can only be established by isolating it from the rock powder by cold hydrofluoric acid. When the material thus obtained is examined in immersion liquids it is found to be composite. The fine fibres of the felt are of extremely small dimensions of the order of a fiftieth of a millimetre, and are composed of both sillimanite and kyanite intergrown. The kyanite is identified by its greater refractive indices, and where thick enough to show double refraction, oblique extinctions up to 30° can be observed.

In the rock kyanite is also seen in isolated grains and as fine prisms springing from the felts; probably sillimanite occurs in a similar fashion. This coexistence together of kyanite and sillimanite is of rare occurrence in rocks and these examples now studied do not provide evidence that one of these minerals is subsequent to the other. The occurrence of both minerals chiefly at grain boundaries is suggestive of development under stress at high temperatures.

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[1] Figures in brackets refer to References at end of paper.

Another group of rocks carrying cordierite together with amphiboles occurs in small cuttings north of Trelease Mill (100 yards and 250 yards north of the Mill) while a small quarry still further north on the east side of the stream and approximately 400 yards south of Trewoon farm has yielded exceptionally fresh material.

The rock types recorded in the *Survey Memoir* from these northern exposures include quartzose hornblende-schists, felspathic hornblende-granulites, and cordierite-anthophyllite-gneisses or granulites rich in fresh cordierite. Flett has noted the similarity of some of these rocks to the cordierite-anthophyllite rocks of Kenidjack in the aureole of the Land's End granite, and as the latter rocks have recently been the subject of investigation [2, 3] this mineralogical resemblance has invited a further comparative study.

Microscopic examination of the rocks from the exposures just indicated shows that the rocks developed may be petrographically divided into the following groups :—

(1) Hornblende-schists with some epidosites.
(2) Quartzose hornblende-schists.
(3) Quartz-hornblende-cummingtonite-schists.
    (3*a*) Anthophyllite-plagioclase-cordierite-granulites.
(4) Cummingtonite-cordierite-granulites.
(5) Anthophyllite-cordierite-granulites.
    (5*a*) Cordierite-biotite-granulites.

These rocks occur together in a banded series, grading one into the other. They are typical crystalline schists and have clearly been recrystallized at high temperatures. Before dealing with their origin a brief account of their petrology will be given.

(1) *Hornblende-schists.*

These rocks form bands interdigitated with the other groups. They are strongly foliated, fine-grained, and in part silky schists with puckered foliation.

The constituent minerals are green hornblende, zoisite, clinozoisite and epidote, ilmenite (with leucoxene): they are in part veined by quartz and prehnite. Some specimens are distinctly banded, strips rich in green hornblende alternating with zoisite and epidote bands.

Associated with them occur rocks rich in epidote (epidosites) also foliated. These bear chlorite, ilmenite, and secondary quartz and prehnite.

(2) *Quartzose hornblende-schists.*

Rocks of this type occur in similar association. They are distinguished by their content of quartz and the usual predominance of plagioclase felspar over epidote minerals.

Long orientated needles of green hornblende are set in a microgranulitic base of labradorite with quartz and there are often irregularly distributed turbid spots of zoisite.

A typical example is figured in the Lizard Memoir (Plate III, fig. 1).

Banding in these rocks may be accentuated by the presence of quartz-rich layers possessing the granulitic texture of the plagioclase areas. Some of this quartz, however, has clearly been introduced, though not subsequently to the metamorphism. The plagioclase-rich bands contain strings of ilmenite plates seen in cross section as rods.

(3) *Quartz-hornblende-cummingtonite-schists.*

These are banded rocks like those of group (2) but are distinguished by the presence of cummingtonite. This mineral may appear among the fibres of green hornblende or may appear in separate bands together with quartz and plagioclase. It is usual for the plagioclase associated with the cummingtonite of these bands to be less calcic (andesine) than that associated with the green hornblendes (labradorite).

(3*a*) *Anthophyllite-plagioclase-quartz-granulite with cordierite.*

A striking rock associated with anthophyllite-cordierite-granulites occurs in the quarry 400 yards south of Trewoon. This is characterized by eyes of a dark coloured mineral set in a finely granulitic base. These eyes which reach up to 15–20 mm. in length and 3–5 mm. in breadth consist of cordierite and its pinitic alteration. They are elongated in the schistosity direction along which anthophyllites up to 1 mm. in length are preferentially orientated. These two minerals are set in a microgranulitic base of labradorite and quartz.

(4) *Cummingtonite-cordierite-plagioclase-granulites.*

These are grey to white slabby granulites rich in quartz, cordierite, oligoclase, cummingtonite and minor biotite, ilmenite (plates), and magnetite.

The cummingtonite (α 1·640, γ 1·665, optically positive) is well orientated and may be in places associated with anthophyllite in parallel growth. In these intergrowths cummingtonite forms the core of the composite prism with a shell of anthophyllite.

The amount and composition of the plagioclase is variable, the latter ranging from oligoclase to basic andesine.

Among these rocks examples occur which are rich in plagioclase and cummingtonite and contain only sporadic cordierite in the form of black splashes set in a white ground.

(5) *Anthophyllite-cordierite-granulites.*

Of the rocks bearing cordierite in this area the most prominent are those containing anthophyllite. The freshest examples come from the quarry in the northern part of the area. Here they are developed in the form of grey granulitic gneisses with dark resinous spots of cordierite reaching 0·5 cm. in diameter. In the exposures on the west bank of the stream north of Trelease Mill slabby banded types are common, the striping being made evident by white bands rich in granulitic quartz with darker bands richer in anthophyllite and cordierite. The foliation surfaces glisten with fine biotite. This striped character is further accentuated where the bands richer in the ferromagnesian minerals have suffered retrograde alteration to chlorite. Crystals of anthophyllite are frequently not visible in hand specimens but types occur in which this mineral is conspicuous in the form of sheaves or *garben* set in a fine base.

Under the microscope the constituents seen are quartz, cordierite, variable amounts of plagioclase, anthophyllite, biotite, and iron ores. Quartz, cordierite, and plagioclase form a granulitic base to larger crystals of orientated anthophyllite (always optically positive). Cordierite, however, also forms porphyroblastic crystals (up to 5 mm. in length) and contains then characteristic enclosures of orientated ilmenite plates.

Some of these larger crystals exhibit features of fracturing and granulitization without any incipient decomposition. Yellow radio haloes around minute zircons are common. The microgranulitic plagioclase varies in composition from oligoclase-andesine to andesine and in some examples becomes an important constituent of the granulitic base. Red-brown biotite is interspersed in this base but may be absent.

An analysis of a representative anthophyllite-cordierite-granulite from the cutting 250 yards north of Trelease Mill has been made in the Geological Survey Laboratory and for its use I am indebted to Sir John Flett.

This rock, the analysis of which is given on page 304 contains quartz, cordierite, and andesine forming a granulitic base to larger anthophyllite crystals. Cordierite is also present as large porphyroblasts up to 2 mm. in length and displays the fracturing and granulation already referred to. Biotite is not abundant and is relegated to bands in the rock, while the iron ores include magnetite and the familiar ilmenite plates. A discussion of this analysis follows on page 304.

To be classified here are a small group of quartz-felspar-granulites, with or without accessory cordierite, containing chlorite pseudomorphous after anthophyllite and partly after biotite. They contain a granulitic base of quartz and oligoclase or andesine and the character of the larger flakes of chlorite indicates their derivation from anthophyllite.

(5*a*) *Cordierite-gneisses with little or no anthophyllite.*

Rocks of this nature resemble very closely the rocks of the main group (5) and are distinguished only by the paucity or absence of anthophyllite. They all contain red-brown biotite, but this is sometimes restricted to definite bands. These rocks pass gradually by increments of anthophyllite into the foregoing types.

TABLE I.

	1	2	2*a*	3	4	5
SiO_2	65·70	65·92	65·21	67·52	48·87	51·00
Al_2O_3	14·24	14·88	13·41	11·45	16·71	20·34
Fe_2O_3	1·51	1·68	2·24	1·72	0·13	2·15
FeO	6·37	4·67	6·23	9·37	12·85	9·10
MgO	4·89	3·52	4·69	7·96	9·60	6·98
CaO	2·39	3·22	4·29	0·19	5·42	3·41
Na_2O	1·96	4·39	1·94	0·22	1·61	2·80
K_2O	0·27	0·18	0·24	0·22	0·27	0·39
H_2O+	1·60	0·69	0·92	1·08	0·99	2·28
H_2O-	0·13	0·09	0·12	—	0·07	0·19
TiO_2	0·94	0·43	0·57	0·15	2·71	1·34
P_3O_5	0·17	0·11	0·14	0·02	0·50	0·24
MnO	0·09	0·17	0·22	0·08	—	0·13
Access.	0·03	0·22	0·24	0·04	0·08	0·04
Total	100·29	100·17	100·46	100·02	99·81	100·39
Sp. Gr.	2·775		—		2·966	—

1. Anthophyllite-cordierite granulite, 250 yards north of Trelease Mill. Anal. C. O. Harvey. Geol. Surv. Lab. [No. 982] with Cr_2O_3 0·01, BaO 0·02.
2. Gedrite-plagioclase rock, Skåtø, Kragerø district, Norway. W. C. Brögger, *Vid. Selsk. Skrifter* M.N.Kl. I, 1934, No. 1, p. 218.

2*a*. Gedrite-plagioclase rock (2) with removal of 24·76 per cent albite.

3. Quartz-cordierite-anthophyllite rock, Carl Filip, Falun Mine, Sweden. W. Larsson. *Bull. Geol. Inst. Upsala*, 1932, 24, p. 118. No. 606.
4. Cummingtonite-anthophyllite-cordierite-plagioclase hornfels, Kenidjack, Cornwall. *Min. Mag.*, 1935, 24, p. 182.
5. Analysis (1) recalculated with removal of 30 per cent quartz.

DISCUSSION.

The rocks of the Trelease Mill area bear witness by their foliated character and evidence of granulitization to the action of strong dynamic forces. Flett has remarked in referring to the anthophyllite-cordierite rocks that they have the appearance of having been much crushed and in places even mylonized. This is very evident in the banded cordierite rocks and comment has already been made on the fractured and granulitized character of the cordierite porphyroblasts. Nevertheless the dynamic movements responsible for the structures of these rocks must have taken place at high temperatures, for the crushing is not accompanied by genuine cataclastic textures nor chemical degradation of minerals such as cordierite; moreover the foliated structure belongs as much to contact minerals like cordierite and anthophyllite as to the other constituents. It would appear that the mineral composition and textures of these rocks were developed while they were being folded at a high temperature. This is in harmony with the view of Flett that the rocks of the northern area (including the hornblende-schist) formed part of the contact aureole of the serpentine, the injection of which took place during the folding of the associated rocks.

When we come to discuss the original nature of the rocks upon which this metamorphism has been imposed certain difficulties become evident. The rocks of the Old Lizard Head Series in their type locality of Old Lizard Head and Venton Hill Point consist chiefly of three groups: (1) mica-schists (with garnet, sometimes andalusite also); (2) quartzo-felspathic granulites (with muscovite, biotite, garnet, and sometimes needles of hornblende); (3) green schists (hornblendic) and quartzose hornblende-schists.

Rocks of group 1 with cordierite, and granulites rich in cordierite with sillimanite have already been referred to as evidence of sedimentary types at Trelease. Rocks of group 3 identified by Flett as thin lava flows, sills, and tuffs are clearly represented among the rocks of Trelease just described.

The problem of the anthophyllite and cummingtonite rocks is less easy. Can these cordierite-bearing types be considered as implying the presence of sedimentary, i.e. original argillaceous material, as the source of their cordierite? When we examine the petrography of these rocks in detail there are certain considerations which are not favourable to this hypothesis. The points to be remarked are chiefly these :—

(*a*) *Mineralogical.*

(1) Cordierite occurs not only with anthophyllite but also with cummingtonite, and the fine granulitic base in which these minerals are set is often rich in plagioclase from andesine to labradorite in composition.

(2) Cummingtonite may appear in association with green hornblende or form separate bands associated with plagioclase. The coming in of cordierite in the latter association provides a link with the hornblende-schist group of rocks.

(3) Even in the more aluminous types rich in cordierite and anthophyllite the rocks are comparatively poor in potash, no orthoclase is present, and biotite is often relegated to definite bands, being absent from others.

(*b*) *Chemical.*

Taking the anthophyllite-cordierite-granulites as a whole they are strikingly poor in potash and compared to quartzo-argillaceous sediments rich in MgO and FeO. These features are brought out in the analysis of Table I (1). This analysis is clearly neither that of an igneous rock nor yet of a normal sediment. The combination of high silica together with the unusual contents of FeO and MgO and low alkalis, particularly potash, attest this abnormal character.

The analysis is compared with that of a gedrite-plagioclase rock described by Brögger from Kragerø, which except in its soda content has a rather striking resemblance to it. This similarity is still more striking if the analysis be recalculated by the simple removal of some of the albite of its dominant plagioclase (column 2*a*).

There are resemblances too with the Falun cordierite-anthophyllite rock (column 3) the chief distinction being the paucity of CaO in the latter. The Trelease Mill rock in fact is intermediate in chemical character between these two rocks.

Both these rocks are regarded as metasomatic products, the Kragerø rock derived by metasomatism of amphibolites (removal of CaO) and the latter by introduction of MgO and iron oxides into acid leptites of the Falun field (magnesia metasomatism).

In the Trelease Mill rocks there appear to be links between the hornblende-schists and the rocks carrying cordierite, stages in which are seen in the incoming first of cummingtonite in association with green hornblende, then in independent crystals—the persistence of medium plagioclase in rocks carrying cordierite, the presence of characteristic ilmenite plates such as to suggest that the cordierite rocks are to be genetically connected with the hornblende-schists. There can be no doubt that much quartz has been introduced into these rocks. This is evident in the veining which is common throughout the group—a veining, however, which is not posterior to the general metamorphism, for the quartz veins and lenses possess the same granulitic texture as the ground mass of the rocks themselves.

The evidence indeed appears to indicate that the anthophyllite- and cummingtonite-cordierite rocks are derived from the hornblende- and quartz-hornblende-schists by metasomatism in which lime chiefly has been carried away and silica introduced.

The process envisaged is closely similar to that described in some detail for the anthophyllite-cordierite rocks of Kenidjack and Botallack [2, 3], where rather similar links with greenstones have been established. At Trelease Mill, however, the rocks are more siliceous, and the original rocks though comprising basic igneous rocks represented by the hornblende-schists may also have included tuffaceous types in which free silica was present. Recognizing, however, that silica has been an important oxide introduced, a closer comparison with the cordierite rocks of Kenidjack can be made if SiO_2 is abstracted from analysis (1), Table I. This is indicated in column (5), the figures of which can be compared with those of column (4) representing a cummingtonite-anthophyllite-cordierite-hornfels from Kenidjack.

Though there is considerable mineralogical similarity in the rocks of the two areas, the textural features differ considerably. The Kenidjack rocks are genuine hornfels recrystallized under the influence of heat, while the rocks of Trelease Mill are crystalline schists, recrystallization taking place in thermal-dynamic metamorphism.

II.

ANTHOPHYLLITE-CORDIERITE-GRANULITES OF PISTIL OGO.

An important group of cordierite rocks has recently been discovered in the type locality of the Old Lizard Head Series in the vicinity of Polpeor Cove, near Lizard town. Rocks of this character are best seen in the shore sections at Pistil Ogo, a cove 200 yards west of the Lifeboat Station at Polpeor, where a variety of cordierite-bearing rocks including anthophyllite-bearing types occur interbanded with the mica-schists and puckered green schists of the Old Lizard Head Series.

The green schists have been fully described in the Survey Memoir. They consist of hornblende- and quartzose hornblende-schists of fine grain with a typical puckered foliation. One additional assemblage has been recognized in association with these rocks, viz. a cummingtonite-plagioclase ± quartz assemblage occurring at Pistil Ogo. These green schists are interpreted as metamorphosed basic flows and tuffs and the cummingtonite-bearing rock is probably to be regarded as a similar type which is impoverished in lime.

The cordierite-bearing rocks of Pistil Ogo are rendered conspicuous by their characteristic weathering. The cordierite appears in dark coloured blotches, lenses, and stripes elongated in the foliation planes. Petrographic examination shows that they possess a considerable variety of mineralogical composition. In addition to cordierite they contain biotite, quartz, acid plagioclase, garnet, anthophyllite, andalusite, and staurolite, but these phases can be grouped according to their typical associations into the following assemblages :—

1. Cordierite ± almandine.
2. Anthophyllite, cordierite, ± almandine.
3. Anthophyllite, cordierite, staurolite.
4. Cordierite, staurolite, andalusite.

} quartz, biotite
acid plagioclase

Comment is necessary only concerning the minerals anthophyllite, staurolite, and andalusite and their fields of association.

Anthophyllite, so commonly associated with cordierite, builds idioblastic prisms flattened on (100) up to 1–2 mm. in length, arranged with their *c* axes in the foliation plane, but the prisms themselves lie criss-cross within that plane. The mineral is coloured and shows an uncommon pleochroism as follows :—

X = yellow, Y = yellowish green, Z = greyish green, absorption $Z > Y > X$. Both elongation and double refraction are positive and the mineral is doubtless a gedrite type with significant alumina as well as iron oxide.

Staurolite forms subidioblastic prisms of smaller dimensions, 0·25 mm. or less, commonly in seams rich in cordierite. The pleochroism is normal. Z = golden yellow, $Y = X$ = pale yellow, optically positive. In addition to cordierite its associates may be either anthophyllite or andalusite.

Andalusite and anthophyllite are never found in close association. If they occur together in a single thin section they are relegated to different bands. They are clearly incompatible and it may be presumed that staurolite, an associate of both, is the phase bridge separating them.

anthophyllite + andalusite → staurolite + cordierite

The assemblage anthophyllite-staurolite-cordierite is not familiar to me among described rocks and the assemblage anthophyllite-staurolite is of rare occurrence.

Broch [4] has described staurolite-gedrite-gneisses from the Nesodden peninsula in the Oslo field as associated with kyanite-staurolite- and gedrite-gneisses and has commented on the fact that kyanite and gedrite are not found together. He has suggested that the rôle of staurolite in relation to these two minerals is similar to that adopted above. In the Orijärvi field Eskola [5] has noted that while sillimanite may appear as a constituent of anthophyllite-cordierite-gneisses, the sillimanite is separated from anthophyllite by a barrier of cordierite. In this case staurolite does not appear but its absence may be attributed either to low iron content of the rocks or to the physical conditions of metamorphism.

That which remains clear from the evidence of the three localities now referred to is the antipathetic character of anthophyllite and the members of the aluminium silicate series of minerals (andalusite, kyanite, sillimanite). The fine banding of the anthophyllite-cordierite rocks with layers of contrasted composition, their field relations, and their general petrography make evident that they represent genuine sedimentary types. Rocks of this composition are probably isochemical with the cordierite-hypersthene-hornfelses of normal contact aureoles. At the Lizard metamorphism was accomplished under the influence of stress combined with high temperature, but the co-existence of andalusite and staurolite suggests, as in the case of the well-known Banffshire rocks, that high temperatures were associated also with fluctuating shearing stress.

CONCLUSION.

The anthophyllite-cordierite assemblage provides a remarkable example of *mineral convergence* in metamorphism. This assemblage is now known to represent the product of metamorphic processes acting upon chemically divergent materials. The sulphide ore fields of Fennoscandia reveal it as a prominent rock type derived by metasomatism of siliceous leptites of volcanic origin, and Cornwall —the Lizard area in particular, as the foregoing account attempts to show—affords examples of its derivation by (*a*) metasomatism of basic igneous rocks and (*b*) regional metamorphism of argillaceous sediments. The growing recognition of the importance of metasomatic processes in metamorphism is nowhere more clearly exemplified than in the studies carried out on the natural history of the anthophyllite-cordierite rocks during the last twenty-five years.

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The Flint Gravel Deposit of Orleigh Court, Buckland Brewer, North Devon.

By INKERMANN ROGERS, Bideford, and BRIAN SIMPSON, University College, Swansea.

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1. SITUATION OF THE DEPOSIT.

THE deposit to be described is situated at Orleigh Court, in the parish of Buckland Brewer, some four miles west of south from Bideford, where it rests unconformably on the steeply dipping Upper Culm sandstones. Its greatest extent is from Orleigh Mill to Yeo Bridge, a distance of about three-quarters of a mile in a north-west to south-east direction, and from this line it extends to the south-west for an average distance of about one-third of a mile, only exceeding that amount to the south of the Higher Lodge. The only extensive section was seen in the Rookery, where 25 feet of material rest on a yellow clay. The highest point reached by the deposit, to the south-west of the Higher Lodge, is about 400 feet above O.D. From this point it slopes to the north-east, extending down to about the 100 ft. contour on the left bank of the River Yeo. It is possible that the north-eastern boundary does not reach such low levels as those indicated on the map, Text-fig. 1, for it is difficult to distinguish the original gravel from relatively recent hill wash; and, without a good deal of trenching or augering, it would not be possible to determine the boundary more closely than has been done in the present work.

2. PREVIOUS LITERATURE.

The presence of this deposit is no new discovery, for it was mentioned by Vancouver (1)[1] as early as 1808. Later, De la Beche (2)

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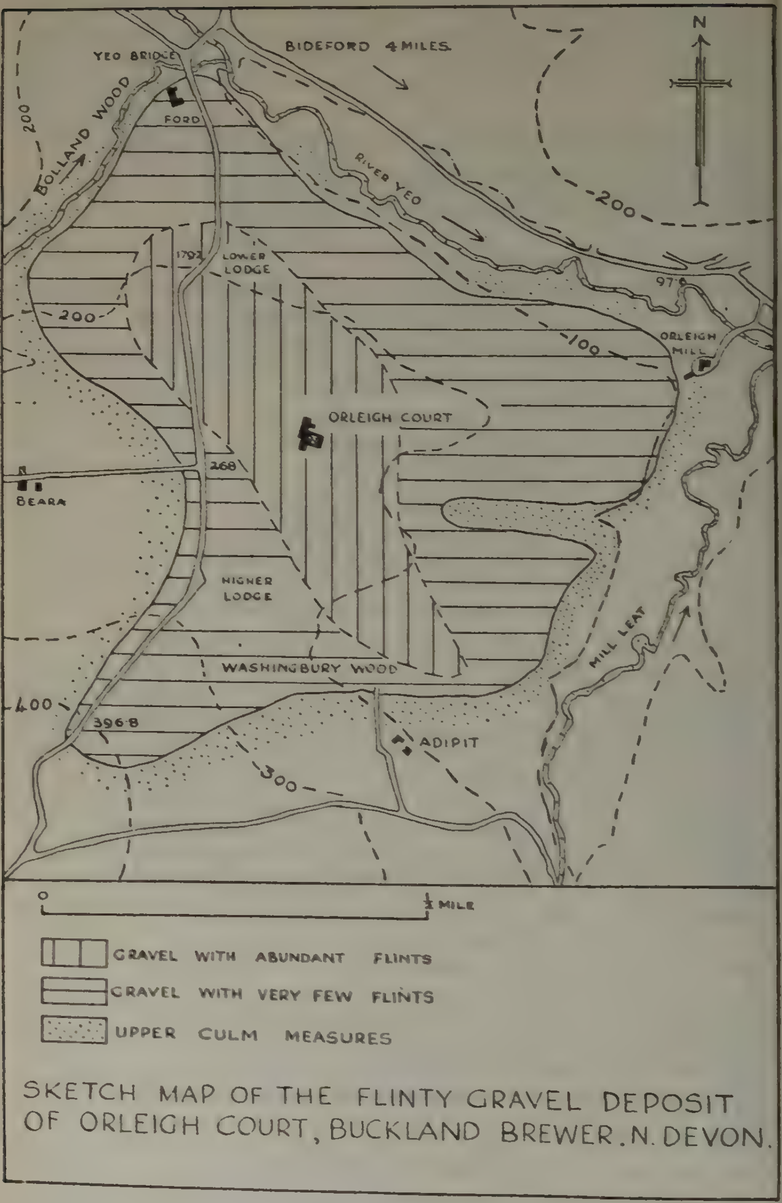
[1] Figures in parentheses refer to References at end.


N
YEO BRIDGE
BIDEFORD 4 MILES
BOLLAND WOOD
200
FORD
RIVER YEO
200
179.2
LOWER LODGE
200
97.6
100
ORLEIGH MILL
ORLEIGH COURT
268
BEARA
HIGHER LODGE
MILL LEAT
WASHINGBURY WOOD
400
396.8
ADIPIT
300
0
½ MILE
GRAVEL WITH ABUNDANT FLINTS
GRAVEL WITH VERY FEW FLINTS
UPPER CULM MEASURES
SKETCH MAP OF THE FLINTY GRAVEL DEPOSIT OF ORLEIGH COURT, BUCKLAND BREWER. N. DEVON.

TEXT-FIG. 1.

described it as "a small patch of Greensand" which "closely resembles those termed the fox mould near Lyme Regis", and recorded *Galerites albogalerus* and *Spatangus coranguinum* from the deposit. He also noted that the flint nodules had suffered little rounding, and used that fact to support his idea that the Chalk had once covered large parts of Devonshire. In 1868 T. M. Hall (3) noted the presence of several iron ores, and described the material as Lower Greensand. Ramsay (4) mentioned the deposit in 1894 when he said "the occurrence of a patch of chert gravel derived from Upper Greensand and resting on the Culm measures at Orleigh Court . . . remains to show that the Greensand once spread westwards so far and probably farther". Ussher (5) regarded the material as Cretaceous, and believed it to be a stage in the Tertiary denudation of this area. In recent years Boswell (6) tentatively ascribed the deposit, on mineralogical grounds, to the Eocene; but Milner in the discussion of that paper favoured a Pliocene age, a conclusion with which the present authors are inclined to agree.

3. THE GRAVELS.

(*a*) *Megascopic.*

The gravels are divisible into an upper and a lower portion on colour alone; the upper, seen in a road cutting south of the Lower Lodge, is a foxy red due to the presence of abundant iron oxide, whilst the lower, seen in a poor section in a road cutting 50 yards west of the Lower Lodge, is buff. A further marked difference is that the lower gravel carries small and relatively few flints, whilst the upper is crowded with flint nodules of various colours, ranging from the common brownish gray through yellowish brown, black, and very rare red varieties. In addition to the flint in the upper gravel there is present an indurated ferruginous grit, in which the larger grains are all extremely well rounded and carry a high polish. In thin section the smaller grains are seen to be more angular. In addition to the quartz there are present in the rock grains of both plagioclase and glauconite; the plagioclase is relatively fresh, but the glauconite, though fresh and bluish green in the centre of some grains, is usually rather altered. This grit is very similar to that found in the Lower Greensand at Leighton Buzzard (7 and 8). In the case of the flint nodules it is certain that some rounding has occurred, but not enough to suggest that any of the material has travelled any considerable distance.

(*b*) *Microscopic Characters.*

A petrological examination of the finer constituents of the deposit revealed appreciable differences between the upper and the lower gravels. In each case the material was sieved through a 40-mesh sieve, treated with ammonia, and finally washed to remove the clay and silt grades. An immediate difference was displayed, for while the lower gravel had relatively small amounts of these grades, the upper gravel carried large proportions of them. Further, the product of washing the lower gravel was a clean sand, whilst the grains of the upper gravel all showed a heavy limonitic coating, and required prolonged treatment with acid before any of the minerals could be identified. In both gravels the grains were ill-sorted, but a marked feature of those less than 0·06 mm. was their extreme rounding and polish, again suggesting a similarity to the sands of the Lower Greensand. Only the heavy minerals possessing marked cleavage or extreme hardness displayed angular outline.

A list of the total mineral content is given in Table 1, whilst the actual percentages among the non opaque heavy minerals is recorded in Table 2.

In our investigation we have failed to recognize the cassiterite, which was recorded from this area by Boswell.

Although flint is abundant and chert is present in the larger pebbles, there do not seem to be any fragments in the material less than 0·06 mm. diameter.

There is little point in describing the minerals in detail, since most of them show normal characters. Mention must be made, however, of the tourmaline, which resembles very closely that seen in many of the igneous rocks of Cornwall (9 and 10). Brown, blue, yellow, green, and colourless varieties are present in subangular and sub-rounded grains. In addition to a well-marked basal cleavage, a distinct vertical cleavage is present, giving a fasciculate appearance to the grains. Occasionally crowds of black opaque inclusions are present.

Zircon is present in very sharp idiomorphs, rounding being very insignificant. The colours range through colourless, yellow, purple, and reddish. Occasional cracking and zoning are seen, and all the characteristic inclusions are present.

The staurolite and kyanite seem very similar to those described by Milner (11) from the Pliocene deposits.

A marked difference between the deposits is the relative proportions of certain species, the lower gravel being characterized by a tourmaline-zircon-andalusite suite, the upper by a zircon-rutile-tourmaline suite. The differences in the rarer mineral species are not to be stressed too much, since the difficulty of cleaning the upper gravel may have caused us to miss some of the rarer constituents of that material.

4. The Fossils in the Upper Gravel.

The most interesting character of the deposit is the presence of numerous fossils in the upper gravel, of which the following is a list :

Echinocorys scutatus Leske (large dome-shaped variety from *mucronata* Zone)
Holaster planus (Mantell)
Phymosoma koenigi Mantell
Cidaris serrifera Forbes

	Table 1.		Table 2.	
Species.	*Lower Gravel.*	*Upper Gravel.*	*Lower Gravel.*	*Upper Gravel.*
magnetite	×	×		
fluorite	—	×		·
garnet	×	×	·	·
zircon	×	×	14	75
rutile	×	×	1·3	7·7
anatase	×	—	·	
tourmaline	×	×	71	5·9
haematite	×	×		
ilmenite	×	×		
limonite	×	×		
quartz	×	×		
corundum	×	—	·	
andalusite	×	×	4·3	4·5
staurolite	×	×	2·8	·
topaz	×	×	1.7	4
brookite	×	×	·	·
hypersthene	—	×		·
enstatite	—	×		·
muscovite	×	—	·	
orthoclase	×	×		
chlorite	×	×	·	·
hornblende	×	×	·	1·1
actinolite	×	—	·	
augite	×	×	·	·
epidote	×	—	·	
monazite	×	—	·	
plagioclase	×	×		
kyanite	×	—	·	

Table 1.—Showing the total mineral content of the two gravels. × = present. — = absent.

Table 2.—Showing percentage ratio of the non-opaque heavy minerals amongst themselves. A dot represents less than 1 per cent.

Echinocorys scutatus var. *depressus* Brydone
Echinocorys scutatus var. *truncatus* Brydone
Micraster coranguinum (Leske)
Micraster praecursor Rowe
Micraster cortestudinarium (Goldfuss)
Marsupites testudinarius (Schlotheim)
Metopaster undulatus Spencer
Offaster pilula (Lamarck)
Conulus albogalerus Leske
Inoceramus inconstans Woods
Coeloptychium deciminum Roemer
Ventriculites radiatus Mantell
Siphonia sp.
Plinthosella squamosa Zittel
Plinthosella sp.
Rhynchonella sp.
Polyzoon
Serpula
Radiolaria
Foraminifera

All the fossils occur as flint casts and many show beautiful preservation of the ornament; in the specimen of *Phymosoma* even the detail of the podal pores is preserved. Most of the forms are completely unabraded and display no marks of water transport; patination when present occurs only as an occasional iron staining. Some specimens show deep corrosion channels, which may well have developed whilst the fossil was in its present locality, while others have a greenish black coating and appear strongly similar to the derived silicified fossils occurring as pebbles at the base of the Woolwich and Reading Beds (12).

The most surprising fact which emerges from the fossil list is the occurrence of forms derived from all the zones of the Upper Chalk from *Holaster planus* to *Belemnitella mucronata*. An almost identical assemblage is recorded by Lee and Pringle (13) from gravels in East Aberdeenshire, where, however, there was no difficulty in relating the fossils to their source in the Cretaceous outcrops along the east coast of Scotland.

5. The Age of the Deposit.

From a consideration of the foregoing pages it is seen that there appears to be present in this deposit material derived from five geological ages as follows:—

1. The indurated ferruginous grit with glauconite is very similar to that seen in the Lower Greensand.
2. The red flint may well have come from the Upper Greensand.
3. Relics of the Upper Chalk occur as silicified fossils, derived from the zone of *Holaster planus* to that of *Belemnitella mucronata*.
4. The greenish black coatings on some of the fossils are very like those seen on the included flints at the base of the Eocene.
5. The mineral content is seen to be closely comparable with that of other Pliocene outliers of the West of England, so far as these have been described.

That this is a derived deposit of at least post-Eocene age seems certain, and the fact that it lies between three and four hundred feet O.D. makes it seem probable that it may once have been part of the 400 ft. platform of the South-West Peninsula in Pliocene times, and may have formed a small basin in this platform; or that it may have formed a more extensive deposit which has since been removed by the post-Pliocene erosion.

The difficulty of assigning a source of origin to this deposit is made manifest by a consideration of the topography of the surrounding country, and the location of probably related rocks to the east, when it will appear that the areas have not been in connection at least since Pliocene times. The topography of the country surrounding Orleigh Court is very typical of the Culm areas, in that the strong upturned beds of sandstone form ridges with an almost east and west trend, whilst the intervening shales and shaly sandstones form the valleys between. The drainage does not invariably follow the valleys in the shale, for streams frequently have breached or are breaching the ridges. The Orleigh Court gravels rest on the north-east flanks of a small hill, once part of a more extensive east to west ridge, but now more isolated by the River Yeo on the north-east, a small stream in Bolland Wood on the west, and the River Duntz on the east. This hill lies on the western side of the big basin formed by the drainage of the Rivers Taw and Torridge, a basin, however, which is much broken up by minor ridges consequent upon the directions taken by the rivers and their tributaries. The eastern area is bounded by Dartmoor Forest on the south, by the upland of Exmoor on the north and in the intervening area by the high land connecting these two.

Rocks from which this deposit may have been derived are, at present, situated some distance away. The Greensand of the Haldon Hills is 43 miles to the south-west; the Chalk in Dorset is over 60 miles south of east from Orleigh Court, whilst the Eocene is over 70 miles away in the same direction.

It will thus be seen that there can have been no direct connection between these areas and Orleigh Court in recent times, at least not since the Pliocene when the present topography was carved out: thus the balance of evidence seems to us to point to a Pliocene age for the Orleigh Court deposit.

Finally we would express our deep thanks to Professor T. Neville George for kindly help and criticism during the work and to Mr. C. P. Chatwin, M.Sc., of His Majesty's Geological Survey, for naming many of the fossils.

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The Distribution of Deep-focus Earthquakes.

By Charles Davison.

DURING the years 1918–1931, there were 270 earthquakes with unusually deep foci, 167 in the Northern Hemisphere, 101 in the Southern, and two with epicentres on the equator.[1] The normal depth of focus is assumed to be about 50 km. or ·008 of the earth's radius. The focal depths of the above earthquakes range from ·005 to ·090 of the earth's radius below the normal depth, or from 50 to 380 miles beneath the surface. Throughout this paper, the depth, when given in terms of the earth's radius, is referred to the normal depth; when given in miles, to the surface of the earth.

The earthquakes may be divided into two groups; the first, 191 in number, with foci at moderate depths, ·005 to ·040 of the earth's radius or about 50 to 185 miles; the second, 79 in number, with foci at great depths, ·045 to ·090 of the earth's radius or about 205 to 380 miles.

On the accompanying maps, small circles represent the epicentres of earthquakes of moderate focal depth, and small black discs those of earthquakes of great focal depth. As a rule, the epicentres lie on or close to curved lines (represented by broken lines on the maps), and the foci, as has been suggested by Mr. H. Honda for the earthquakes of Japan (*Nature*, 136, 1935, 783–4), are probably situated on corresponding deeply-seated fissures or series of fissures. Whether they are continuous from or near the surface to the great focal depths is of course uncertain, but it is worth noticing that the focal depths at one epicentre in the Hindu Koosh mountains are estimated at ·020, ·025, ·030, and ·035 of the earth's radius and that earthquakes of normal focal depth are associated with 57 per cent of the epicentres of deep-focus earthquakes.

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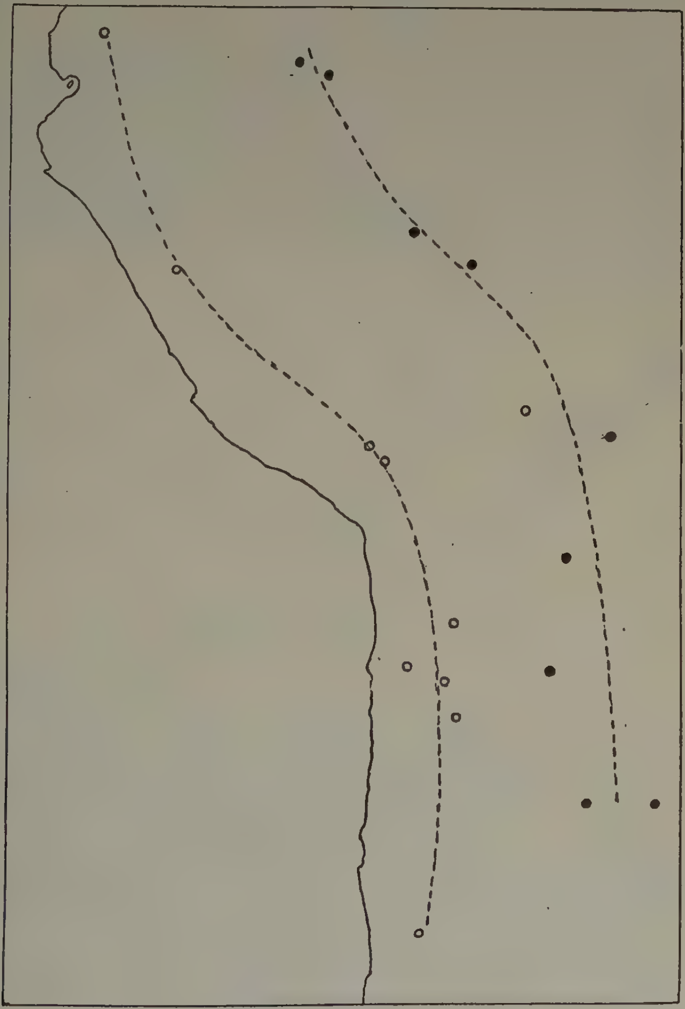
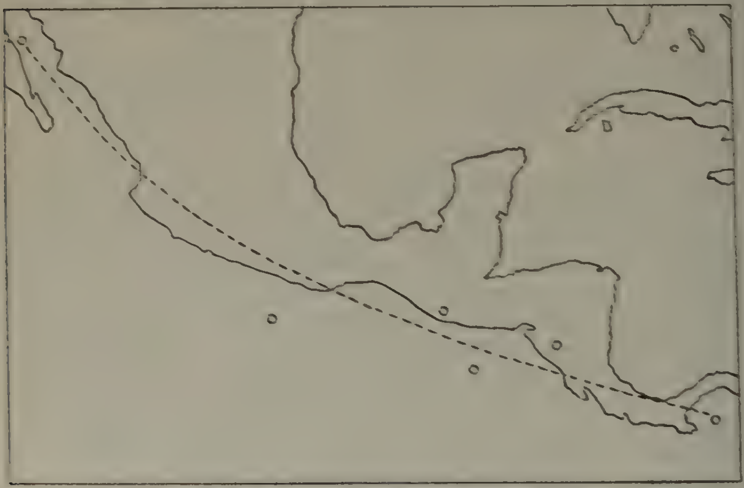
[1] *Intern. Seis. Sum.*, 1918–1931; H. H. Turner, "Catalogue of Earthquakes 1918–1924" (*Brit. Ass. Rep.*, 1928, pp. 241–304); and Miss E. F. Bellamy, "Catalogue of Earthquakes, 1925–1930" (*Brit. Ass. Rep.*, 1935, pp. 230–304); and *Index catalogue of epicentres for 1913–1930* (County Press Office, Newport, I.W.).



TEXT-FIG. 1.—Ecuador, Peru, and Chile.

With a few exceptions, the epicentres of deep-focus earthquakes lie in seven regions, two continental and five insular, all of them along or near the margins of the Pacific. In four regions, the numbers of epicentres known are at present small, and, as the records for years to come are added, some of the curves here drawn (Text-figs. 2, 3, 5, and 6) may require some change.

(1) *Ecuador, Peru, and Chile.*—In this region, the epicentres of deep-focus earthquakes lie on or near two lines that are similar in form and roughly parallel to the coast-line (Text-fig. 1). One of these lines is on the east side of the Andes at an average distance of about 140 miles from the coast, and the epicentres connected with it are entirely those of moderately deep foci. The other lies at an average distance of about 470 miles to the east, and with it are associated all the earthquakes possessing very deep foci. Along the former line, the average depth of the foci is ·028 of the earth's radius or 140 miles. The depth, however, varies along the line. In the northern half from 0° to 18° S., the mean depth is ·040 of the earth's radius; in the southern half, from 18° to 35° S., it is ·019. Also, if the line were continued northwards to lat. 3° N., it would pass through the epicentre of an earthquake of focal depth ·045. Along the second line, the average depth of the foci is ·076 of the earth's radius or 325 miles. The depth varies slightly along the line, from ·072 in the northern half to ·083 in the southern. Both lines, if they are correctly drawn as continuous, are more than 2,000 miles in length.

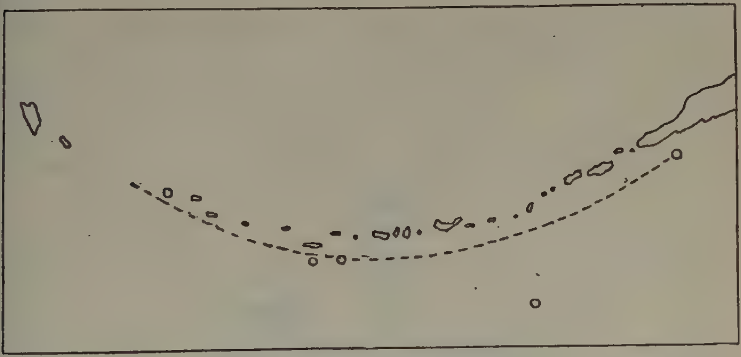


Text-fig. 2.—Central America and Mexico.

(2) *Central America and Mexico.*—The distribution in this region is more simple or it may be that the interval of fourteen years is

too short to disclose it fully. All the six epicentres correspond to moderately deep foci, the average depth of which is ·014 of the earth's radius or about 85 miles. While the depths of the terminal foci are ·010, the average depth in the central portion is ·016. The line passing through or near the epicentres is about 2,500 miles long and, roughly, outlines the coast (Text-fig. 2).

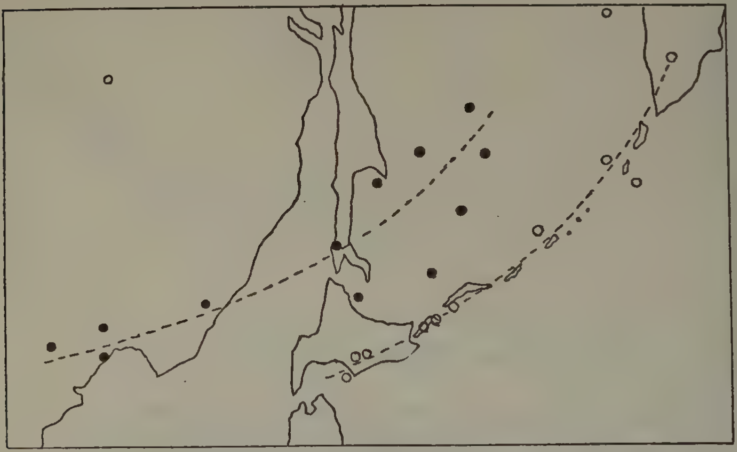
(3) *The Aleutian Islands.*—In this region, there are only five epicentres, all associated with moderately deep foci, the average depth of which is ·011 of the earth's radius or 75 miles, the individual depths, from east to west, being ·005, ·010, ·020, ·010, and ·010. The line passing through or near the epicentres is about 1,200 miles in length and follows rather closely the curve of the Aleutian arc, at a short distance to the south (Text-fig. 3).



TEXT-FIG. 3.—The Aleutian Islands.

(4) *The Kurile Islands.*—This region closely resembles that of Ecuador, Peru, and Chile. There are at least two lines along which the epicentres cluster, both slightly convex to the south-east and nearly parallel to one another (Text-fig. 4). The outer one follows the arc of the islands. It is at least 1,000 miles in length and is associated only with foci of moderate depth, the average depth being ·017 of the earth's radius or about 95 miles. The second line, about 1,200 miles long and 320 miles to the north-west of the other, is marked by earthquakes with very deep foci only, the average depth being ·061 of the earth's radius or about 270 miles. Between the two lines there may be a third, about 120 miles from the latter, and, like it, associated with very deep foci, the average depth of which is ·057 of the earth's radius or about 250 miles. An unusual feature of both outer and inner lines is that the average depth of the foci is less in the central portion than near the ends. In the outer line, the mean depths in the north-east, central, and south-west sections are ·022, ·010, and ·018 of the earth's radius; in the inner line they are ·068, ·048, and ·065.

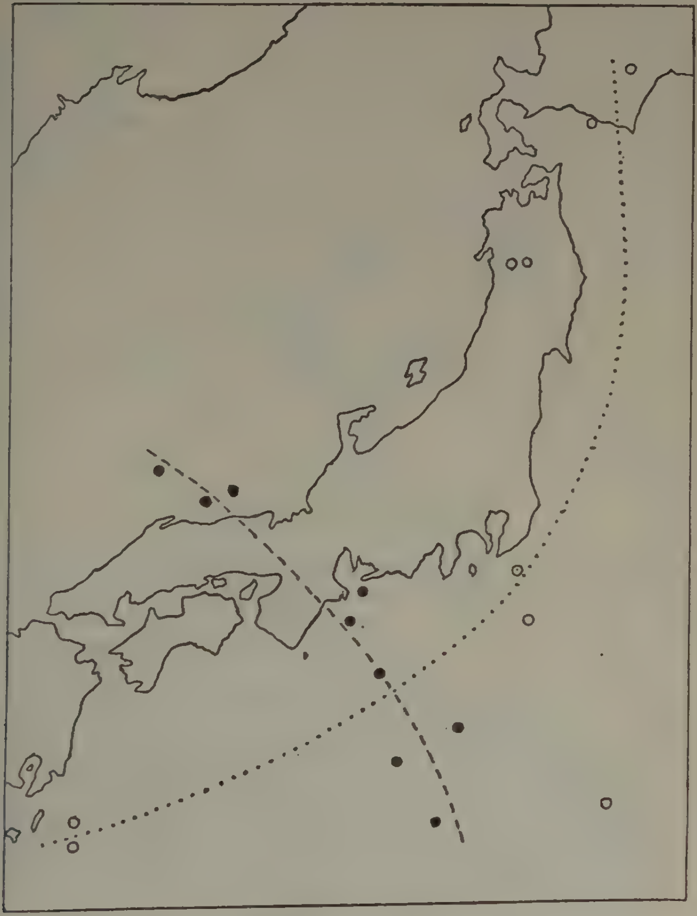
(5) *Japan.*—The deep-focus earthquakes of the Japanese Islands reveal another mode of distribution. The only line that can be drawn definitely is one associated with nine very deep focus earthquakes (·045 to ·060 of the earth's radius). The line, which is about 500 miles in length, agrees approximately with that traced by Mr. Honda. It is slightly convex to the north-east and crosses the island arc at right angles, passing about 70 miles to the south-west of the great fault of the Mino-Owari earthquake of 1891. The average depth of the foci along it is ·053 of the earth's radius or about 235 miles, and this average holds also in each of three sections, in the centre and at either end. There are also three pairs of epicentres corresponding to moderately deep foci, one in the south of Hokkaido, the others submarine and lying to the south of the Boso peninsula and Kiushiu Island. These epicentres are close to a curve parallel to the Japanese arc (represented by the dotted line on the map), but there are not enough points to determine its course. It may be noticed, however, that the epicentres of several destructive earthquakes are close to the line as drawn, while those of earthquakes of normal depth are clustered along or near it.



TEXT-FIG. 4.—The Kurile Islands.

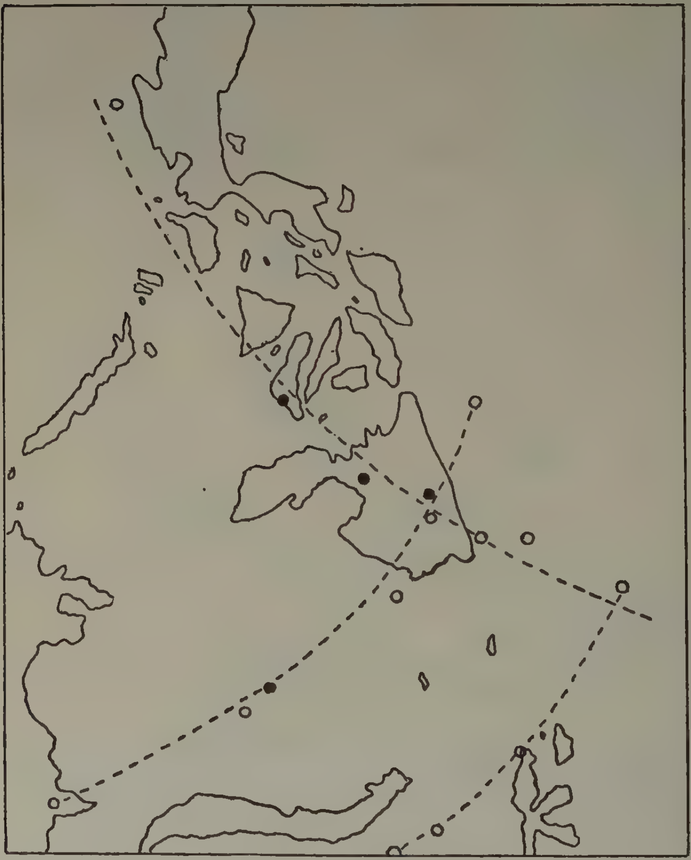
(6) *The Philippines.*—The distribution of epicentres in these islands combines the features of the last two regions. It possesses an outer line, corresponding to earthquakes of moderate focal depth, and an inner parallel line and a transverse line, both of these depending on earthquakes of all focal depths. The outer line is about 500 miles long, and the average depth of the foci connected with it ·030 of the earth's radius or about 150 miles. The inner line, about 850 miles in length, is 340 miles from the

other, and the mean depth of the foci along it is ·039 of the earth's radius or about 185 miles. The transverse line, about 1,000 miles long, is slightly convex to the south-west, and the average depth of the foci along it is the same as that of the foci along the inner curve. In both of these lines, the epicentres belonging to very deep foci lie near the central portions. In the inner line, the mean depths in the north-east, central, and south-west sections are ·025, ·052, and ·015 of the earth's radius; in the transverse line, the mean depths in the north-west, central, and south-east sections are ·020, ·073, and ·029.



Text-fig. 5.—Japan.

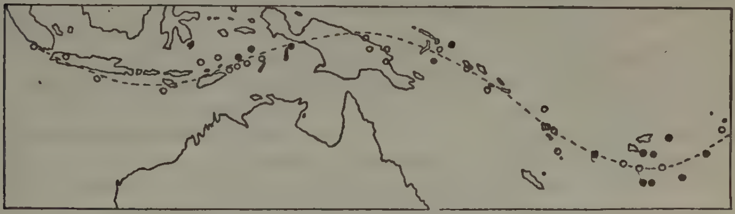
(7) *The East Indies, etc.*—Yet another mode of distribution marks the deep-focus earthquakes of the East Indies and the adjoining islands (Text-fig. 7). The epicentres are confined to a single line sinuous in form and, if continuous, of unusual length, not less than 6,500 miles. The line at first is submarine and follows the arc of Sumatra, Java, Sumbawa, and Flores. Then, after crossing New Guinea, it runs along the arc of the Solomon Islands, New Hebrides, Fiji Islands, and Samoa. The foci that determine the course of the line vary in depth, twelve ranging from ·050 to ·070 of the earth's radius and thirty-three from ·013 to ·040. The average of all the depths is ·035 of the earth's radius or about



Text-fig. 6.—Philippines.

165 miles. The epicentres corresponding to very deep foci divide the line into six sections in which, from west to east, the average focal depths are ·029, ·045, ·030, ·045, ·024, and ·054.

It is interesting to notice the distribution of ordinary earthquakes (1918–1930) in connection with that of deep-focus earthquakes. For each region, two maps have been drawn. Dividing a region into nearly equal areas by lines of latitude and longitude five degrees apart, the number of epicentres in each area is entered at its centre in one map, and similarly the number of earthquakes in the other. Lines drawn through or near the centres of the areas with the highest numbers may be taken to represent roughly the surface courses of the fissures in which most of the earthquakes originate. It seems unnecessary to reproduce these maps, but it should be stated that, in every region, the two lines are in close agreement. In one region (Ecuador, Peru, and Chile), the lines follow the course of the coast-line; in three others (Central America, the Aleutians, and the Kuriles), and perhaps also in Japan, the line of moderately deep foci; in the Philippines, the transverse line of foci of all depths; while, in the East Indies and islands to the east, they lie almost wholly along the sinuous line.



TEXT-FIG. 7.—East Indies, etc.

Comparatively few of these earthquakes were of destructive strength. In Ecuador, Peru, and Chile, the epicentres of such earthquakes are close to the line of moderately deep foci and to the coast-line, especially to the latter; there are none near the line of very deep foci. In Central America and Mexico, they lie close to the one line of moderately deep foci; and, in the East Indies, to the sinuous line in those sections between the epicentres connected with very deep foci. In the other regions, they are too rare or too scattered to reveal any definite distribution.

The chief points of difference between the two sets of deep-focus fissures are:—

(1) The mean depth of focus ranges from ·011 to ·028 of the earth's radius in the line of moderately deep foci, and from ·053 to ·076 in that of very deep foci. In the lines including all focal depths in the Philippines and East Indies, the mean depths are ·039 and ·035, or nearly the same as the average depth (·033) for the whole world.

(2) Moderately deep focus earthquakes are subject to a well-marked period of 14·8 days with epochs close to the times of new and full moon, and this shows that the movements along such fissures are mainly upward. On the other hand, very deep focus earthquakes show no sign of such a period, that is, there is no general trend, upward or downward, in the movements that occur along them.

(3) The epicentres of ordinary earthquakes and also of destructive earthquakes are numerous about the lines of moderately deep foci, and, except in the Philippines, comparatively rare along the lines of deeper foci.

(4) The foci of ordinary earthquakes with the same epicentres as moderately deep focus earthquakes are in action about twice as frequently as those with the epicentres of very deep focus earthquakes, the average numbers of earthquakes per epicentre during the years 1918–1930 being 2·4 and 1·3. It should, however, be noted that the average numbers of deep-focus earthquakes per focus are nearly the same in both classes, namely, 1·6 and 1·7. Thus, it would seem that the line of moderately deep foci belongs to a younger stage of growth than the line of very deep foci.

Now, in at least four of the seven regions, the coast-lines or insular arcs are parallel to, or follow, the lines of moderately deep foci, and their forms no doubt are determined to a great extent by the movements along the corresponding fissures.

The South American region is one of great interest. In this, there seem to be fissures of three distinct ages: (1) the fissure of very deep foci, probably the oldest of all, still active, though now affecting very slightly the form of the surface features; (2) the fissure of moderately deep foci, along which many upward movements occur that are not yet without influence on the growth of the crust, and, in the southern and shallow half of which, ordinary earthquakes are specially numerous; and (3) the fissure or fissures along and near the present coast-line, in a very active stage of growth, but in one so early that they cannot yet, so far as we know, be regarded as deep-focus fissures.

Is it too much to infer that the two deep-focus fissures trace the forms of ancient coast-lines; that, during the ages that have elapsed since the deeper fissure came into existence, the shore of the South American continent has travelled 600 miles to the west; in other words, that continental masses do not drift, but that their forms in successive ages are determined by those of great fissures that penetrate the crust to depths of several hundred miles?

A New Record of Boudinage-structure from Scotland.

By Robert Walls, Beit Scientific Research Fellow, Imperial College of Science and Technology, London.

THE peculiar tectonic structure called "boudinage" by Lohest (5, pp. 471–2),[1] has recently been found in Unst, Shetland Islands, by Professor H. H. Read (8, pp. 134–8), who has also noted its occurrence in the Durn Hill quartzites of Banffshire (9, p. 471). What would now be termed boudinage-structure was seen by Ramsay in North Wales, and was described in 1866 in these words (6, and fig. 18): "In the great quarry west of the Ffestiniog and Trawsfynydd fault the cleavage dips from 45° to 50° north-west, the inclination of the beds being about 35° in the same direction, and a greenstone dyke runs through them between the cleavage-planes . . ., bulging and thinning off in a rapid succession of oval-shaped masses of 3 or 4 feet in length. Associated with it are quartz veins occurring principally at the points between the separate bulgings of the greenstone."

These appear to be the only records of this interesting structure from Great Britain. "Beds of limestone exhibiting a succession of swellings and constrictions" described by A. Harker from Ilfracombe, Devonshire (3), lack the distinctive quartz partitions of classic boudinage-structures, and are not accepted as such by a writer familiar with the Belgian occurrences (1, p. 107).

During an investigation of the andalusite-schist series of North-East Scotland, the writer has found boudinage-structures at several points on the Aberdeenshire coast. The first example was seen at Pittulie, 2¼ miles west of Fraserburgh, in 1934. While mapping the cliff-section between Whinnyfold and Forvie Ness (see sketch-map, Text-fig. 1) in 1936, excellent occurrences were met with north of Slains Castle. These will be described first.

Geological Setting.—The coast between Forvie Ness and Whinnyfold is shown on Sheet 87 (Peterhead) of the 1 in. maps of the Geological Survey of Scotland, and most of the boudinage-structures fall within the 6 in. sheet Aberdeenshire XXXIX S.E. The cliffs ascend to 80 feet or more in places, but are generally fairly accessible, and exposures are good. Inland, very little can be seen.

The rocks are a slightly metamorphosed series of Dalradian age, the equivalents of the Boyndie Bay Group of Banffshire (7, pp. 55–9), with quartzites and spotted- (andalusite-) schists as principal members. The latter rocks represent argillaceous sediments in which a regional metamorphism has developed andalusite, cordierite, and biotite. In the field they are deep blue-grey to black in colour, with a lustre on some surfaces caused by many small mica-plates. The spots, which are up to 1 cm. in length, are not so conspicuous as those in the Boyndie Bay beds at Banff, on account of the darker colour of the matrix. The spotted rocks are often thick-bedded, and frequently alternate with layers that do not carry andalusite. Many of these are siltstones, thinly banded in black and white, which form subordinate but very widely-spread rocks throughout the andalusite-schist area.

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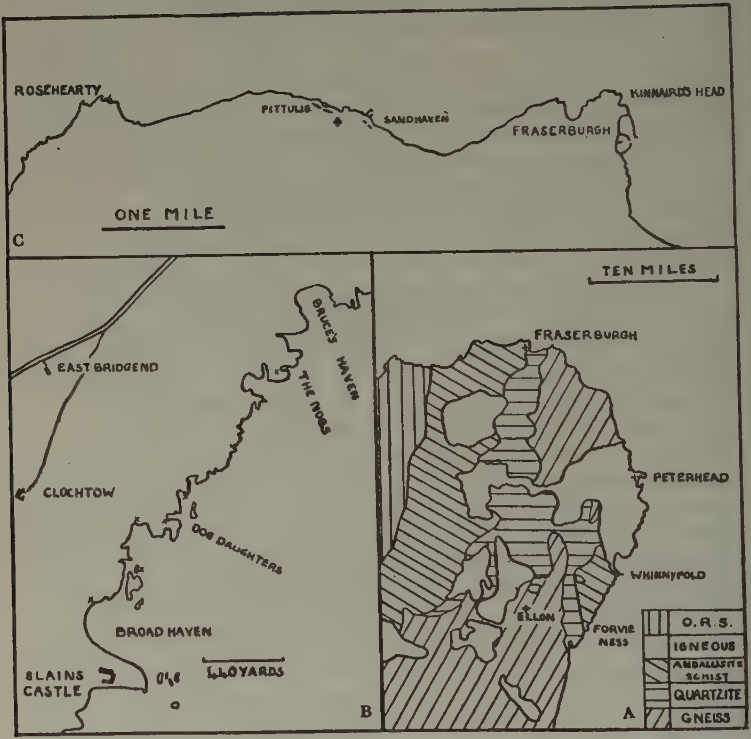
[1] Numbers in parentheses refer to the References at end of paper.

Most of the quartzites are grey or yellow, and are fairly fine-grained, though coarser pebbly grits occur, of a type common in Aberdeenshire and Banffshire (7, pp. 52, 54). They are usually thickly bedded between bands of siltstone or spotted rock. Graded-bedding is found in some of the grits, but current-bedding has not yet been seen.



TEXT-FIG. 1.—(*a*) Geological sketch-map of North-East Aberdeenshire. (*b*) Sketch-map of part of the Aberdeenshire coast between Whinnyfold and Forvie Ness. (*c*) Sketch-map of the Moray Firth coast west of Fraserburgh.

In the southern part of the coast-section dips are often about east or west, at low angles, but in the northern part northerly and north-easterly dips become frequent. Where the cliffs expose only a strike-section the beds may appear to be in continuous sequence, but in many places dip-sections expose the noses of recumbent folds, the median planes of which dip at low angles. In those exposures where dip-sections are not available, it is not safe to assume that any bed is uninverted. An attempt was made to find depositional features in a bed whose relation to the folding was unambiguous, in order to determine the attitude of the sheet as a whole, but without success.

Several systems of joints traverse the rocks, and along some of them joint-caves and gullies have been eroded. The trend of the joints has influenced the shape of the coast-line, and the form of many of the low islets just off shore. Some of the rocks show a poor cleavage, which, in many parts of the area, lies at low angles to the horizontal.

The Boudinage-structures.—The coast between Slains Castle and Bruce's Haven, $1\frac{1}{4}$ miles north-north-east (see sketch-map, Text-fig. 1*b*), exposes many boudinage-structures. Excellent, but somewhat inaccessible, examples are seen in the low cliffs of Broad Haven, 300 yards north of Slains Castle, where three thin quartzites are affected. A section more convenient for study is found just above high-water mark on the south-western side of the small promontory "The Nobs", about 1,200 yards east of East Bridgend (see Text-fig. 1*b*).

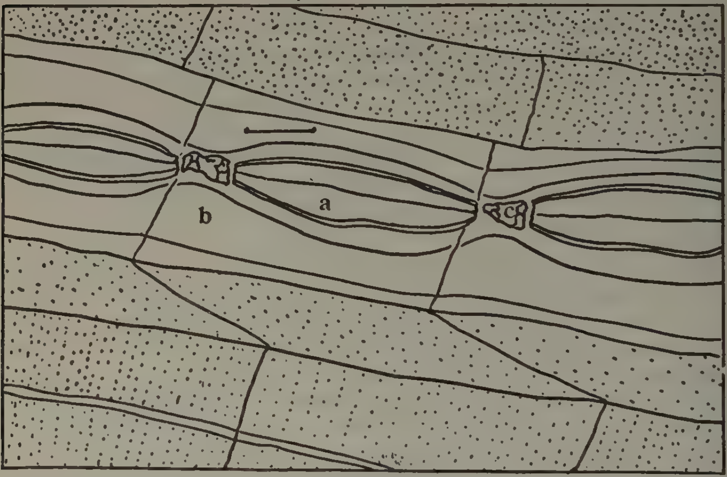
Here, on the west side of a small embayment, about 25 feet of rock rise from the sea in a series of broad steps. Many beds, which are seldom more than 5 feet thick, are composed of fine quartzite, with others of rather sandy spotted rock and layers of fine, banded siltstone. The dip is west 35° north, at 10–12°.

About 10 feet above high-water mark is a prominent, slightly banded, yellow quartzite, the strike section of which displays a series of lenticles—the boudinage-structures. Individual boudins in the central part of the exposure are about 3 feet wide, and have a maximum thickness of 10 inches (see Text-fig. 2). On tracing this bed to the south-west, the boudins diminish in width and thickness, and finally pass into a 3 in. band of quartzite only rarely displaying the structure.

In the better developed parts, the quartzite layer is set in a slightly banded spotted rock, which extends about 15 inches above and below the boudins, and which is followed in turn by beds, 2 feet thick, of fine quartzite. Eight to ten inches of vein-quartz occur between pairs of boudins; the masses are irregular in shape and differ from the lenticular quartz partitions of the Belgian structures (1, pl. iv, fig. 5). The banding in the spotted rock, through a thickness of about 6 inches, bends in smooth curves toward these quartz-filled nodes. A banding seen in the boudins is bent in conformity with the external form (see Text-fig. 2).

A second line of smaller boudins occurs about 5 feet below the main band.

From the sections available it can be seen that the boudinage-structures at The Nobs have not the regular subcylindrical shape of those from the classical localities (1, pl. iii, fig. 1), but resemble the " quartzites en amandes " figured by J. Gosselet from Rocroy, Belgium (2, pl. v, fig. 6). The lenticular form is well shown in an occurrence about 700 yards E.S.E. of the farm Clochtow (see Text-fig. 1*b*). Here, to the south of a conspicuous joint-gully, at the head of the inlet " Dog Daughters ", is an area of spotted rock, about 20 ft. by 40 ft., whose surface is disposed in a series of small rounded hollows, the impressions of an eroded set of boudins. Those not yet eroded are seen in the face of a low ledge on the north side of the area.



Text-fig. 2.—Boudinage-structure at The Nobs. (*a*) Quartzite boudins, their banding schematically indicated. (*b*) Fine siltstone, with banding deflected towards the nodes of the boudinage-structure. (*c*) Vein-quartz masses between the boudins. Dotted areas = quartzite. The horizontal line represents one foot. From a photograph.

At the western end of the exposure several of the hollows have a fairly uniform arrangement as a series of furrows and ridges, trending west 40° north. The crests of the ridges are about 8 inches apart, and rise 3 or 4 inches above the bottoms of the hollows. These ridge and furrow systems cannot be traced for more than a few feet along their axes, and, over much of the exposed area, give place to small sub-oval hollows, which maintain an approximate parallelism of their greatest lengths. Individual hollows, which may be a foot across, sometimes contain two or more deeper depressions.

In the Ardenne region, cases are known of two sets of boudinage structures at right-angles in the same bed; Wegmann (10, p. 479) speaks of their exposed upper surfaces as showing "chocolate-tablet structure". While the Aberdeenshire examples are not so regular as to merit this appellation, yet it is probable that their lenticular forms result from a similar cause, the successive operation of stresses in two approximately perpendicular directions.

Large-scale Lenticular Structures.—On Text-fig. 1*b* small crosses mark the sites of well-developed boudinage-structures, but many more are present. From Slains Castle to The Nobs most thin quartzite bands that lie between softer beds have been more or less affected, and an obscure lenticular structure is seen in many beds of grit of considerable thickness. Such a case occurs in a small headland 100 yards north-north-east of Dog Daughters, where a doubly-tapering quartzite band, about 20 feet long by 5 feet thick, is flanked by two incomplete lenticles. Masses of vein-quartz form the actual junctions of the grit beds, that to the north being the better developed of the two. Andalusite-schist occurs above and below the grit, and its banding is slightly diverted towards the quartz-masses. This seems to be a true large-scale boudinage-structure; unfortunately, it cannot be traced beyond this headland, and no comparably developed occurrence was met with elsewhere.

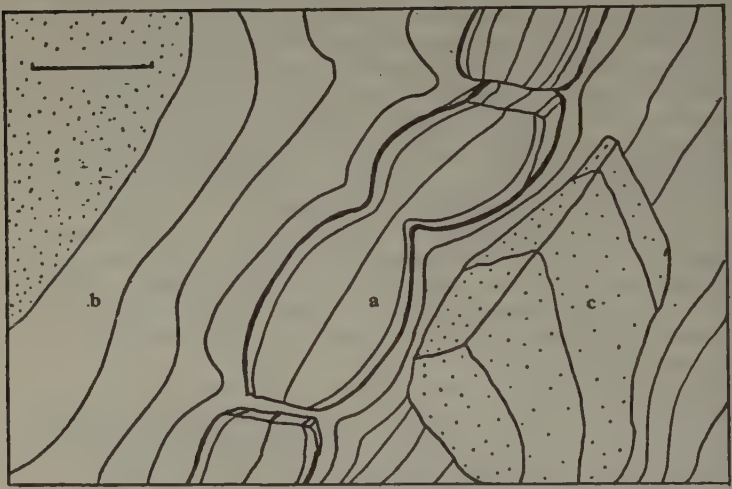
Boudinage at Pittulie.—The small example of boudinage at Pittulie (see Text-fig. 1*c*) is found just below high-water mark on the west side of a low crag, about 140 yards north-west of the church. As an example of the structure it is unimportant, but it is interesting because of its proximity to some folded junctions of hard and soft rocks.

The beds exposed on this part of the Moray Firth coast are members of the same series of Dalradian sediments as those described above, and lie on the eastern limb of a complex syncline (9, p. 475). At least two orders of minor folds are present; at this point the dip is about 15° to the north-east, but it swings to the east within a short distance.

Rising from the pebbly beach, the crag exposes about 3 feet of coarse andalusite-schist followed by about 6 inches of a fine-banded rock in which andalusite is only rarely developed. An irregular band of quartzite comes next, with an ill-expressed lenticular structure. About 3 inches of banded siltstone separate this quartzite layer from the boudins.

A partly weathered-out boudin just below high-water mark can be recognized by its composite appearance in strike section. The two parts, the larger a foot, the smaller 8 inches in width, have a maximum thickness of 6 inches, but taper to half that at their junction. The free ends of the boudins also taper off, and are separated by a short distance from adjacent boudins (see Text-fig. 3). The quartzite displays a laminated structure, which curves in conformity with the exterior surface. Most boudins in this bed are of the normal, doubly-tapering form seen in the Aberdeenshire examples, but one, about 2 feet in width, is divided into several parts by thin walls of vein-quartz, which do not quite reach the surrounding siltstone. Above and below these partitions, the margins of the boudin, and the banding of the siltstone are slightly incurved. This resembles Wegmann's figure of "classic boudinage" (10, p. 483).

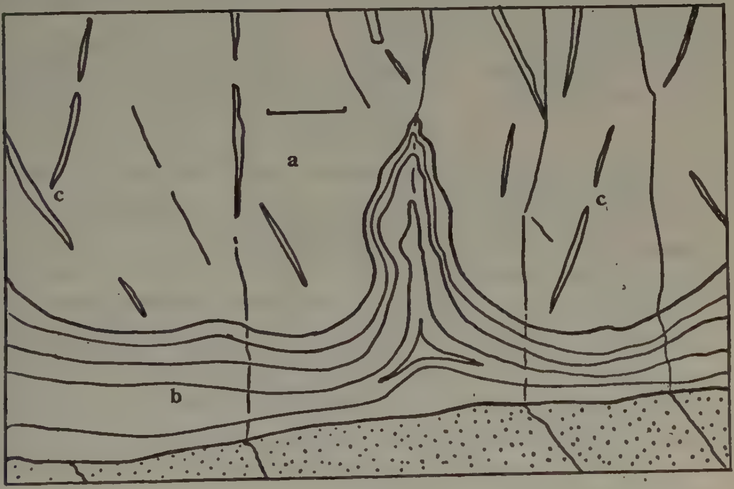
About a foot of banded siltstone, with few andalusites, separates the boudins from the overlying bed of coarse quartzite, 8 feet or more in thickness. The lower surface of the latter bed shows a series of downwardly-convex curves, separated by sharp cusps, into which the siltstone is forced up. This is well seen at a number of points on the landward side of the low crag, and is illustrated in Text-fig. 4. Quartz-veins, 2 or 3 inches wide, traverse the quartzite in several directions, and are particularly numerous above the upfolded siltstones.



TEXT-FIG. 3.—Boudinage-structure at Pittulie. (*a*) Double boudin of banded quartzite. (*b*) Finely banded siltstone, the banding bent towards the nodes of the boudinage-structure. (*c*) Weathered-out mass of quartzite below the band of boudins. Dotted area represents the overlying quartzite. The horizontal line is 6 inches long. From a photograph.

These infolds resemble Holmquist's figures (4, p. 7) of the compressed junctions of competent and incompetent beds. It is possible that the lateral forces responsible for the development of boudinage in the underlying thin bed of quartzite may have been transmitted largely through the overlying thick bed, but the tectonics of the area have not been sufficiently investigated to determine this.

Some General Considerations.—Recent writers on the subject, whose views have been summarized by Read (8), agree that boudinage-structures arise through the extension of the beds involved. There is also agreement in the view that the relatively more plastic beds have flowed under the influence of stress, fracturing and dragging apart the enclosed more resistant band. Corin's explanation (1, pp. 109–113) considers that the projection, on to the plane of the beds, of the force causing flow in the less rigid material, lies in a direction perpendicular to the axes of the boudins. Read has shown in Unst that a force, whose projection on to the plane of the bed was parallel to the axes of the boudins (i.e. parallel to the dip-direction), has caused extension in the strike-direction.



TEXT-FIG. 4.—Junction of competent and incompetent beds, Pittulie. (*a*) Quartzite. (*b*) Finely banded siltstone, (*c*) Quartz-veins. Dotted = coarse andalusite-schist. The horizontal line is 6 inches long. From a photograph.

Although the beds in which boudinage-structures develop react to external forces as more rigid bodies than the enclosing rocks, yet they have a certain degree of plasticity. Corin, indeed, believes that the rigidity diminishes outward from the axis of the bed, the margins of which have the plastic properties of the surrounding rock. The double boudin at Pittulie (Text-fig. 3) shows that the quartzite here exhibited a plastic behaviour. The narrow neck between the two parts is not severed by a quartz-filled fracture of the type that occurs between boudins proper, and the laminations in the quartzite curve smoothly from one part to the other. It seems that at this point the two masses were drawn asunder, while at the same time the thickness of the neck diminished, but that extension stopped before rupture took place.

Perhaps in some cases the first effect of tension in the rigid bed, caused by the drag of the plastic rock, is the formation of more or less regularly spaced contractions in the thickness of the bed, at which points the latter subsequently breaks. In other cases, with rocks of greater rigidity, fracture may occur first, followed by arching of the relatively unsupported faces, in the manner suggested by Wegmànn (10, p. 482) and Read (8, p. 137). The examples of boudinage-structure in Aberdeenshire are not sufficiently clearly related to any tectonic event to make a decision on this point possible, and a study of their development is hindered by their advanced state of deformation. It is possible that the application of the methods of petrofabric analysis may throw light on this problem.

In conclusion, the writer wishes to acknowledge his indebtedness to Professor H. H. Read, who introduced him to North-East Scotland and to boudinage, for much helpful and critical discussion.

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REVIEWS.

INTRODUCTION TO THEORETICAL SEISMOLOGY. Part I: Geodynamics. By Professor J. B. MACELWANE. 8vo, pp. x + 366, with 15 plates and 67 text-figures. New York: Wiley and Sons; London: Chapman and Hall, 1936. Price 30*s*.

THIS is a long-expected book, since Part II, Sohon's *Instrumenta Seismology*, was published four years ago. There was a need for a connected exposition of the theory of seismology, some of which is in Love's *Elasticity*, while the rest has to be sought in scattered papers. Most of the book is mathematical; it is correct, but in places seems needlessly laborious. The P, S notation is attributed on p. 147 to Jeffreys; the first use of it appears to be in Knott's *Physics of Earthquake Phenomena*, 1908. Practically the whole of the discussion of observed data is contained in pp. 198–330. Results are given for the velocities of waves in the upper layers, without statement of the uncertainties, though these have been determined for several of the series of data used. The intermediate layer is called "the basaltic layer of Jeffreys", who, however, has repeatedly pointed out that its properties are not those of crystalline basalt and prefers to express no definite opinion about its nature. It should be noticed that the estimate of the velocity of P* in the Tyrol earthquake quoted is due to a serious mistake in calculation, and that Gutenberg's Californian estimate is not attributed by him to P*. The structure of the earth as revealed by seismology is discussed at some length. Chapter X deals with determination of epicentres and Chapter XI with deep-focus earthquakes. The theories of the two types of surface waves are given, but there is no discussion of dispersion (group-velocity is not mentioned) and therefore of Stoneley's estimates of the thicknesses of the upper layers. The method of determining the uncertainty of an estimate from observations is vaguely referred to standard text-books, though it is one of the chief needs of seismology at the present time.

On the whole this is a book for mathematical physicists, and if the reviewer was writing for them he would be more favourable. The less satisfactory parts, however, are just those that might be expected to contain what the geologist wants to know.

H. J.

INTERPRETATION OF SCHISTOSITY IN THE ROCKS OF OTAGO, NEW ZEALAND. By F. J. TURNER. Transactions of the Royal Society of New Zealand, vol. 66, pp. 201–224. 1936.

THIS paper records the first results of the application of the methods of fabric analysis, whose importance is now becoming recognized, to one of the problems presented by a metamorphic series in yet another country. A clear summary of the older theories of the significance of schistosity is followed by an account of the conclusions reached by Sander on the basis of his studies of the fabric of schistose rocks. In applying these conceptions to a study of the Otago schists, partial analyses of the grain fabric have been made, using an ordinary petrographic microscope. The evidence obtained is considered to exclude the possibility of load metamorphism, and to favour the view that schistosity developed parallel to the original bedding during a deformation governed by low-angle thrusting.

F. C. P.

EARTHQUAKES. By NICHOLAS HUNTER HECK. pp. xi + 222, with 88 text-figs. Princeton University Press, 1936. London, Humphrey Milford. Price 16*s*.

THE author is chief of the Division of Seismology in the United States Coast and Geodetic Survey, and President of the International Seismological Association. In the former capacity he is responsible for most of the collection and interpretation of earthquake data in the United States, though California and the Jesuit Seismological Association have separate organizations and adequate co-operation is maintained. His book is mainly descriptive, and deals with the visible effects of earthquakes, types of instruments, appearance of records, design of buildings, and location of earthquake epicentres. Complicated theory is avoided. Particular attention is naturally given to American data, but this is no defect, because the author has first-hand knowledge and the results are in general agreement with those found in other parts of the world. The disturbances along faults and the effects on buildings are illustrated by a large number of striking photographs. The variation of felt intensity is shown in many maps (some of which have the lettering too small to be read comfortably without a magnifier). Accounts are given of many great earthquakes outside America, and of seismological organization in other countries. These are brief but adequate for ordinary purposes. Photographs and descriptions of the main types of seismograph are given (but why is the Quervain-Piccard instrument shown out of focus ?). The author writes with considerable caution ; his " further investigation is needed " often marks some point where a statement has been made and repeated on inadequate evidence.

The reviewer has detected few errors. On p. 5 it is perhaps a matter of definition whether the material that made the Oppau explosion was a high explosive or not ; the explosion was the first intimation of its possibilities in that direction. The seismic waves from it were too small to be recorded in England. On p. 34 the idea that conduction of heat from the interior of the earth has an appreciable influence on surface temperature reappears. On p. 215 the idea of the liquid core of the earth is attributed to Knott ; if it is to be attributed to any single person, it should be to R. D. Oldham. Poisson, who predicted theoretically the two types of bodily wave, should have an appearance in the historical chapter. On p. 122 we find the expression " this earthquake disturbed objects not in equilibrium ". The misuse of the term " equilibrium ", borrowed from dynamics, is too common. A body not in equilibrium is one already in motion or having an acceleration, and it would be impossible to decide whether the subsequent motion of such a body was due to the earthquake. Presumably the author means " objects with a small range of stability ". We may hope that these minor lapses will be corrected in another edition ; meanwhile the book can be recommended.

H. J.

THE LARGER FORAMINIFERA OF THE LOWER MIOCENE OF VICTORIA. By I. CRESPIN. Palaeontological Bulletin No. 2. pp. 1–13, plates 1–2, maps 1. Published by the Department of the Interior. Commonwealth Government Printer, Canberra. 1936. Price not stated.

THE details in the above are copied from the title-page; the information about the printer is included, because the title chosen for this series—"Palaeontological Bulletin"—gives no clue even to the country of origin, and it is only from the status of the printer that we can deduce that this is an official publication of the Commonwealth of Australia.

It is a useful compilation, giving a bibliography, a list of the species and the localities at which each occurs (the localities are shown on the map). "No attempt is made at systematic descriptions. . . . It is more in the nature of an attempt to help the field geologist to locate himself in the Tertiary sections throughout Victoria". One regrets the modest nature of the aims of the author, although possibly the time is not yet ripe for a systematic monograph.

The field geologist could possibly identify his foraminifera from adequate figures, even in the absence of systematic descriptions; but although the two plates are excellent (considering their mode of reproduction), and the photographer is to be congratulated on his work, only one of the twenty-seven figures shows a section, the remainder being external views. No one would attempt nowadays to identify species of *Lepidocyclina*, for instance, without sections; and the absence of figures of them (possibly from motives of economy) is to be deplored.

Although the palaeontologist is apt to groan under the burden of the large number of periodicals which he ought to read, the advent of this new publication can be greeted with congratulations, since it marks a further stage in the recognition of the Commonwealth of Australia of the importance of palaeontology.

A. G. B.

A STRATIGRAPHICAL CLASSIFICATION AND TABLE OF TANGANYIKA TERRITORY. By F. B. WADE. Bulletin 9, Department of Lands and Mines. Geological Division, Dar es Salaam, 1937. Price 4*s*.

IN this publication the Chief Geologist sums up the present state of knowledge of the stratigraphy of the Territory, which is complicated, as it includes Quaternary, Tertiary, Recent Volcanics, Cretaceous, Jurassic, Palaeozoic (Karroo and Bukoba Systems), and a large development of the Pre-Cambrian. The greater part of the Bulletin is occupied by a "Stratigraphical Lexicon", which defines and describes all the rock-groups at present distinguished, and there is a large folding table in a pocket in the cover. All this will be most useful to geologists in general, as well as to specialists on Central Africa.

R. H. R.

CORRESPONDENCE.

THE GIRVAN-BALLANTRAE SERPENTINE.

SIR,—There is no "question at issue" between Dr. J. G. C. Anderson and myself. Argumentation is doubtless essential in the conduct of the affairs of the state and men, and in the legal arenas. But in any of the fields of inferential scientific inquiry progress depends rather upon the production of fresh evidence. It was for the purpose of pointing to fresh evidence that I wrote my paper (GEOL. MAG., January, 1937); not because I had any hypothesis either to sustain or subvert. Dr. Anderson says that he cannot observe the foliation of the Ballantrae serpentine. Far be it from me to say any unkind thing to an enthusiastic young worker. Therefore I shall only reply to Dr. Anderson that if, at low tide, he will examine carefully the curving and polished sides of the red serpentine skerries on the coast south of Burnfoot he will there easily discern the serious inaccuracy of his statement.

Dr. Anderson's description of the shore section at Pinbain, cited as affording "unequivocal evidence" relating to the geological age of the serpentine, surely requires emendation. Thus Dr. Anderson states that south of an upstanding band of porphyritic spilite "Peach and Horne have mapped a belt of serpentine exposures. These can be locally separated into two rather narrow bands . . . South of the more southerly band rises a small knoll of non-porphyritic spilite with doubtful pillow structure . . . On the south side of the knoll serpentine is seen in contact with the lavaform rock." My inference is that this knoll must have serpentine upon both its north and south sides. I leave it to Dr. Anderson to clarify this obscure part of his narrative.

I did not put forward the thesis that the serpentine had been metamorphosed. What I intended and attempted to make clear was this, that the parental peridotite must have experienced a long and complicated metamorphic history prior to its hydration and conversion to serpentine. A closely similar story, I have lately come to believe, probably attaches to the peridotite of the Lizard. Thus I now incline to regard the peridotite of the Lizard as an integral component of an original banded and stratified complex, all the members of which, in the first place, were folded and metamorphosed together. Certain of the felspar-bearing rocks have been transformed to hornblende-schists, but the peridotite by long subsequent hydration, after the manner corresponding to Ballantrae, has simply withdrawn from the metamorphic picture. This interpretation, it must be indicated, is consistent with the forty-years-old opinion of Mr. Howard Fox and Sir Jethro Teall that the Lizard serpentine forms "part and parcel of the foliated series to which the hornblende-schists belong" (Ref. *Quart. Journ. Geol. Soc.*, 49, 200).

D. BALSILLIE.

ROYAL SCOTTISH MUSEUM,
EDINBURGH.
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ORIGINAL ARTICLES.

The Base and Top of the Coral-rock in Barbados.

By C. T. Trechmann.

(PLATE XII.)

BARBADOS, 21 miles long, 14 miles wide, rising to 1,101 feet, is probably the most considerable Pleistocene non-volcanic bleb on the face of our planet, at least in the Antillean region. Other islands may show coral-rock or wave-cut terraces going up to higher levels, but none are so clearly of Pleistocene date as is Barbados.

Three different explanations have been advanced to account for the structure of this terraced island:—

(1) J. B. Harrison and A. J. Jukes Browne's theory that each terrace was once a fringing reef and that each step in ascent is older than the one below.

(2) J. W. Spencer's view that there are limestones of Oligocene age resembling the Antigua limestone near Consett Point and at higher levels, and that a great unconformity separates the older from the newer limestones.

(3) My theory that practically all the coral-rock covering had been formed before the uplift commenced; that the uplift was not directly vertical but was accompanied by lateral thrusts from the west and south, and that the southerly or Christchurch anticline was later than the main uplift and was accompanied by further thrusting from the south.

The last mentioned theory has lately received encouragement from an entirely independent source, that of soil maturity; S. J. Saint writes [1]:—

"It also follows that the soils which have been longest exposed to atmospheric conditions will be the most mature; hence, the oldest soils will be those found at the greatest elevations. It is, therefore, not surprising that the physical and chemical properties of the various soil types correspond with their elevation above sea-level. The reason why the soils of the Christchurch ridge are less weathered than the soils at the same elevation on the main part of the island is explicable on the geological evidence of Trechmann. The properties of the soils on the Christchurch ridge yield evidence in support of Trechmann's view of the uplift of the island."

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[1] *Agricultural Journal*, Dept. of Science and Agriculture, Barbados, 3, No. 3, July, 1934. 34.

In 1932 I wrote that at the base of the coral-rock but independently of altitude a few fossils suggestive of a Pliocene age were collected, especially in the south-east near Consett Point.[1] The search at the base of the coral-rock has now been extended to all parts of the island where it is exposed, and I find that when one gets accustomed to searching at this horizon a fauna occurs in it strikingly different from that in the main mass of the coral-rock above. Unfortunately the fauna is scanty and the condition of the fossils often bad.

This fauna, together with observations on certain beds later than the coral-rock and their bearing on the question of the uplift form the subject of the present paper.

POST-CORAL-ROCK FORMATIONS.

The semi-marine post-coral-rock beds may be termed the "Helix" beds after the common *Helix* (*Caprinus*) *isabella* which occurs in most of them. These beds seem to be confined to the west, south, and east coasts of the Christchurch Anticline where they form a sort of veneer near the coast; and to the south-east coast between Whitehaven and Ragged Point, this being the only locality where they are massive enough to merit the description of a formation.

Probably similar beds once existed on the main part of the island, but being of a thin or non-consolidated character they may long ago have been removed by denudation.

At the north end of Barbados it is doubtful if there are any beds corresponding to the post-coral-rock deposits in the south. The peculiar features in this part of the island will be referred to later, but there are no rising terraces and there has certainly been no thrusting from the north.

At many places around the island between tide marks beds of consolidated sand, often remarkably evenly stratified, a few feet in thickness are being formed at the present day but are not discussed in this paper.

THE SOUTHERN ANTICLINES.

The Christchurch anticline or ridge rises to about 400 feet altitude and occupies most of the southern part of the island extending east and west for about seven miles, and north and south for some two miles. This uplift is complicated by minor irregular north-east to south-west folds or undulations especially towards its east and west ends, and by depressions which may be due to minor faulting or to erosion along the crests of the lesser folds. A denuded fold exposes a patch of Oceanics at Hopefield and Loamfield. The two or three lower terraces especially near the south-east coast are very perfect; but inland, although three or four more rising terraces can be traced, they are more obscure and tend to merge into one another.

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[1] "The Uplift of Barbados," GEOL. MAG., LXX, 1933, 46.

The northern edge of the Christchurch anticline is a fairly straight east to west line and slopes rapidly down with a small escarpment to St. George's Valley, a broad syncline separating it from the main uplift of the island. The Christchurch anticline is notable for the almost complete absence of ravines; those that occur are either shallow or short; a short rocky gully exists near the south-east coast at Paragon near Long Bay. This lack of ravines forms a great contrast to the main portion of Barbados the higher part of which is noticeable for its numerous deep rocky gullies, which moreover have a tendency often to turn suddenly at right angles. Several of these gullies continue almost down to sea-level on the west side of the main portion of Barbados; the sudden turning may have been induced by the up-folding of the coral-rock.

At the extreme south projecting end of Barbados a third anticline, which one may call the South Point Anticline, nearly two miles in length from east to west, seems to be in process of rising, though judging from Carib Middens with pottery and shell implements, which exist close to the shore, there has not been much rise in the last 300 years. The coral-rock here rises to a height of about 85 feet and has a rolling or low dome-like surface and slopes down northwards to the southern edge of the Christchurch anticline. This southernmost uplift also has coastal veneers of post-coral-rock beds, for instance, at the south end of Oistin Bay, near the South Point Lighthouse, and in Long Bay.

NORTH END OF BARBADOS.

The flattish unterraced north end of the island is peculiar in some ways; whether it has emerged more recently than the terraced anticlines in the south is uncertain. It has some minor ravines but inlets of the sea, such as River Bay, seem to be due to the washing out of softer beds rather than to stream erosion.

Near the extreme north point, at Cluffs, the characteristic base of the coral-rock with *Haliotis* occurs. The same basal junction is found at Crab Hill, Mount Poyer, and Spring Hall, round the edges of inliers of Oceanics and Scotland beds. On the south side of Gay's Cove at the foot of the steep slope towards Pico Teneriffe a similar basal bed with *Haliotis* can be seen; but along the three miles or so of the north-east coast from the middle of Gay's Cove towards the Animal Flower Cave the base of the coral-rock is different. No true basal bed with the characteristic fossils is to be seen, but instead the Oceanic beds pass up into a mixture of coral-rock and oceanic chalk containing corals and mollusca like those found in the true coral-rock.

The explanation seems to be that the line of inland cliffs that extends from Pico Teneriffe to Mount Gilboa and the rounded slopes near Spring Hall and Mount Poyer represent more or less the original slope of a coral reef, scarped at a later date by faulting and coastal erosion. It seems that thick coral-rock may never have been deposited at the north-east corner of the island, or that the underlying Oceanics were washed up, and interfered with the growth of the corals.

The coral-rock at this corner of the island looks like a talus that has accumulated off the slope of the main reef; we see very large corals growing almost through the whole section of the cliff among bedded masses of corals and shells with redeposited Oceanic chalks and marls.

Platform erosion has, however, affected also this part of the island, and the covering of coral-rock has been worn away in places, exposing Scotland beds and Oceanics. Off the coast at the present day a well-defined shelf is being cut; the cliffs are 40–50 feet high and about a quarter of a mile out to sea a small rugged islet of coral-rock stands up from the outer edge of the platform.

THE SOUTH-EAST CORNER OF BARBADOS.

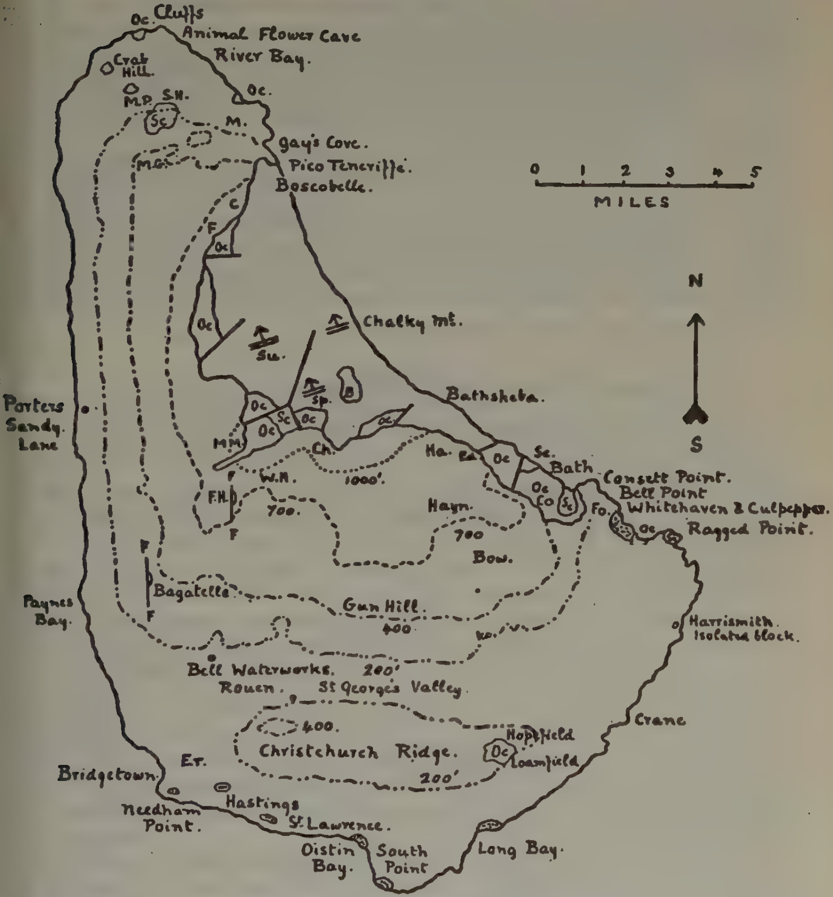
This area is the most problematical in Barbados geology; it is the area where the basal coral-rock is thickest and is the only locality where the post-coral-rock beds are at all massively developed.

The shape of the promontories of Consett Point, Bell Point, and Ragged Point that project into the Atlantic suggests that a number of faults converge here and their continuation and direction inland and possible influence on the rising terraces has been engaging Dr. H. Huber's attention. At Codrington College and Bath Beach to the north-west, old coral-rock lies more or less horizontally at sea-level or some height above sea-level. Its position relative to the main coral-rock escarpment that rises towards St. John's Church must certainly be due to uplifting or down faulting, but the direction of these faults has not yet been definitely traced.

The section of old-looking coral-rock in the sea cliff on the south side of Bell Point (Fig. 2) shows a good deal of minor thrusting and fracturing suggesting that the coral-rock may have resisted pressure from the west or south and become fractured or sheared in the process.

ORIGIN OF THE TERRACES.

In 1933 I mentioned the possibility that fault scarps may have been responsible for some of the higher terraces. Dr. Huber's survey of Barbados for oil prospects, assisted by evidence from borings, has now made this a certainty in several instances. He has found two strips of Oceanics exposed by north–south faults in the midst



TEXT-FIG. 1.—Sketch-map of Barbados. Showing coral-rock contours at 200, 400, 700, and 1,000 feet. Sc. Scotland Beds. Oc. Oceanic Series. Localities: M.P., Mount Poyer. S.H. Spring Hall. M. Position of undercut mushroom-like rocks. M.G. Mount Gilboa. C. Cherry Tree Hill. F. Farley Hill. Ca. Canefield. Ch. Chimborazo. W.H. Welshman's Hall. Ha. Hackleston's Cliff. Ed. Edgecliff. Hayn. Haynesfield. Bow. Bowmanston Waterworks. Fo. Fortescue. Er. Erdiston. Su. Sunbeam. B. Bissex Hill. M.M. Mount Misery. F.H. Fortress Hill. Co. Codrington College. Dotted patches near Whitehaven and around the southern coast indicate the post-coral-rock deposits.

of the coral-rock area, one at the foot of Fortress Hill and another at Bagatelle. The straight north–south western side of the island and its parallel rising terraces in itself suggests post-coral-rock faulting. He has also postulated several important cross-country faults and thinks that the lines of straight cliffs have been produced by fault action, while some of the irregular lines of inland cliffs are the result of sea erosion. At the same time many of the terraces are clearly the result of wave cutting, indicated by isolated stacks of rock still left standing. In Long Bay in the extreme south three or four such stacks 15 feet or so in height stand up near the outer edge of a wave-cut platform.

A feature noticed by me some years ago, that the terraces are often higher at the outer edge and slope down towards the next inland cliff is explained as due to later up-tilting. Terraces often tend to rise and sink gradually or to merge laterally into one another, a feature which seems to be due to uplift either by faulting or simple up-bending of the beds at the same time as the terraces were being cut by periodical rises of the sea-level.

THE BASE ON WHICH THE CORAL-ROCK WAS DEPOSITED.

The oldest beds of Barbados, the Scotland Series, are largely estuarine in origin and have been thrown into a complex of folds whose strike is predominantly E.N.E.–W.S.W. This does not coincide with the present alignment of the lesser Antillean islands or the hypothetical Antillean Arc, but agrees more with the strike of the northern range of Trinidad, and of older beds in the Virgin Islands and Central America and Venezuela ; it probably indicates the framework of an old pre-Miocene " Antillean continent ". It has of course nothing to do with the Pleistocene uplift of Barbados. On the faulted and denuded edges and ridges of the Scotland beds follows the Joe's River Clay, probably a product of late post-Eocene mud-volcanoes. Above these the Oceanic beds were deposited. The latter vary from 0–1,000 feet in thickness, are probably of Miocene age and are considered to be of abyssal origin. They were faulted and denuded by submarine erosion before the commencement of coral-rock times.

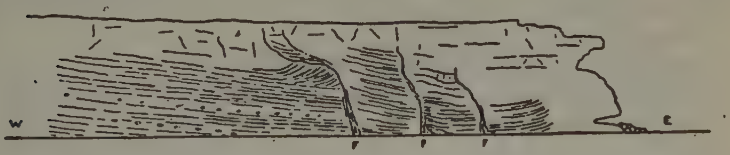
Coral-rock conditions seem to have been initiated on a submerged surface consisting of ridges of massive Scotland beds alternating with areas or humps of Oceanics, comprising both the softer chalks and the harder beds of the Bissex Hill type. This submerged platform may have lain in places at a depth of 200 to 1,000 feet.

The basal beds of the coral-rock, the Amphistegina and lithothamnial platy limestones with *Haliotis*, Terebratulids, etc., seem to have exercised a sort of levelling-up process, filling up the hollows and lapping up against the submarine ridges, the tops of some of which may have nearly reached the surface of the sea. This levelling-up process having been completed, the main coral-rock commenced to grow. No reason is apparent why it started to grow; one can only observe in most sections that the basal beds give place in a few inches or feet to the normal rock with large coral masses and associated mollusca of Pleistocene aspect.

THICKNESS OF THE CORAL-ROCK AT SEA-LEVEL.

The tantalizing question how thick the coral-rock is at sea-level has been partly answered. Just west of Porter's Sugar Factory about the middle point of the straight western side of Barbados and about 100 yards inland from the sea, where no coral-rock but only beach sand is seen, Dr. Huber has caused a boring to be sunk. The result is a surprise; the coral-rock continues much deeper below sea-level than we expected.

At a depth of 344 feet basal *Globigerina* beds similar to those on Bissex Hill were met with. Dr. Huber attributes the higher 80 feet of unconsolidated material to a post-coral-rock formation. The actual solid coral-rock commenced at a depth of about 90 feet. This gives us the considerable thickness of 264 feet for the coral-rock prior to its elevation.



TEXT-FIG. 2.—Sketch of cliff on south side of Bell Point promontory, S.E. Barbados. This bedded lower coral-rock with lines of hollow nodules passes up into massive coral-rock. F.F. Fractures and dislocations which may be due to a resistance to thrusting coming from the west and south-west side of the island.

Hitherto all well-sinkings near sea-level had gone down to where the water becomes brackish and then stopped. This boring has given significant and important information.

With such a thickness of coral-rock below sea-level a considerable thrust could presumably be exerted against the island, and if a lubricant to assist the thrusting be required, the soft Oceanics or softer Scotland beds might fulfil that rôle.

THE BASE OF THE CORAL-ROCK.

The following localities show junctions where one can study the basal beds and the formations on which they rest.

Northern Area.

Cluffs: on Oceanics.

River Bay to Gay's Cove: on redeposited Oceanics, an abnormal junction.

Gay's Cove to Pico Teneriffe: on Oceanics.
Crab Hill: on Scotland sandstones, an inlier.
Mount Poyer: on Scotland sandstone and shales, an inlier. (M.P. on map.)
Spring Hall: on Scotland beds, an inlier. (S.H. on map.)

Around the Elevated Scotland Escarpment.

Cherry Tree Hill: on Oceanics. (C. on map.)
Farley Hill: on Oceanics. (F. on map.)
Caledonia or Sturge's: on Oceanics.
Foot of Fortress Hill: on Oceanics, a faulted inlier. (F.H. on map.)

South-Eastern Area.

Bath beach: on Oceanics, an abnormal junction.
Codrington College: on Oceanics, obscured junction. (Co. on map.)
St. Mark's Church: on Oceanics.
Consett Point: on Oceanics.
Whitehaven: on Oceanics and Scotland beds.
Ragged Point: on Scotland sandstones.
Hopefield and Loamfield: on Oceanics, an inlier.

South-Western Area.

Bagatelle or Parkham Park: on Oceanics, a faulted inlier.

Cluffs.

This bay near the north point of Barbados shows basal coral-rock resting on Oceanics; the basal bed passes imperceptibly up into the main coral-rock, as follows:—

	Feet.
(*a*) Hard coral-rock	50
(*b*) Layers of lithothamnial limestone with clusters of small Terebratulids	2–5
(*c*) Beds of conglomerate made of clay-ironstone pebbles and other remanié debris mixed with pieces of Oceanic chalk, in places full of irregular worm tubules filled with marl. *Haliotis*, various Lamellibranchs, Pteropoda, etc.	5–10
Irregular unconformable junction.	
(*d*) Oceanics: *Globigerina* chalks with thin layers of brown material largely minute fragments of volcanic glass	30

Crab Hill.

A small inlier of Scotland sandstone dipping steeply is overlain and surrounded by old bedded coral-rock, hard and lithothamnial. It reaches 6 feet in thickness and has a thin remanié layer at the junction and rounded masses of Scotland beds occur some distance up in the coral-rock. *Meiocardia* is not uncommon here, with a few *Amphisteginae*.

Near Caledonia or Sturge's. (N.W. of Ch. on map.)

On the escarpment overlooking the Scotland district at about 1,050 feet altitude a small cliff across a canefield exposes 10 feet or so of the base of the coral-rock. It has a conglomerate of clay-ironstone pebbles at the base, and rests on Oceanic chalks which show cone-in-cone structure. *Amphistegina*, *Turbo*, one *Haliotis*, Terebratulids, etc., were found here. On the west side of the road a fault brings down cliffs of massive coral-rock with much-dissolved corals and casts of mollusca apparently of living species.

Bath Beach.

Near Bath Station a patch of coral-rock appears a little above sea level and seems to be *in situ*.

	Feet.
Coral-rock consisting of calcareous hardened sand bed, porous and rubbly at the base. No large fossils, but a few *Amphisteginae*, echinoderm spines, etc.	15
Oceanics, brown, rather nodular, largely made up of volcanic ashy material	30

Codrington College. (Co. on map.)

The college stands on a platform of horizontal coral-rock which seems to be in place and not slipped. In a ravine near the college a very hard platy lithothamnial limestone with few traces of fossils rests on Oceanic chalks.

Ragged Point (Fig. 4).

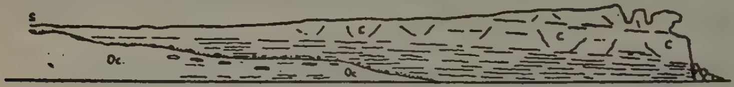
Spring Bay just south of Ragged Point offers an impressive section of old and basal coral-rock. The massive Scotland grits and associated beds stand out as a bold ridge and headland near the lighthouse, while on the south they sink rapidly down the dip being about 45° north. The basal coral-rock beds have filled up the hollow and lap up against the ridge, but die out before reaching the top, where the junction consists of a jumble of coral-rock masses and large angular Scotland fragments mixed with Pleistocene mollusca. Down the slope, however, the platy basal coral-rock is well exposed, and has at its base a conglomerate of clay-ironstone and other nodules. The fossils here comprise *Haliotis*, Terebratulids, etc., and a few *Amphisteginae*. The cliff is about 85 feet high, the lower 50 or 60 feet are basal coral-rock and the upper 25 feet or so ordinary massive coral-rock.

Consett Point.

The section in the railway cutting here is not very clear but about 25 feet of old hardened calcareous sand-rock in which hollow "potato stones" tend to develop dip 30° southwards, but the apparent dip may be current bedding. This passes up imperceptibly into ordinary massive coral-rock with *Livonia pica*, large corals, etc. Further down the cutting *Amphistegina* limestone rests on Oceanic chalks. The bedded sand-rock yields *Pectens* of pre-Pleistocene aspect, including fragments of a very large species resembling *P. pittieri.*

Whitehaven (Fig. 3).

Along the northern boundary of Whitehaven Bay the basal coral-rock forms a line of cliffs, and laps up westwards on to a rising mass of Oceanic chalks. On top of the rise of Oceanics the coral-rock becomes very thin and marly and contains a variety of *Strombus gigas* and a few *Amphisteginae.* Passing north-east along the line of cliff the basal bed gradually thickens and comprises up to 20 feet of platy lithothamnial limestone which merges up into hard coral-rock with massive corals and casts of mollusca. At the junction with the Oceanics there is a well-defined band of clay ironstone, Oceanic, and Scotland fragments. This is a good collecting ground for the basal fauna, and I found my first specimen of *Haliotis* here.



Text-fig. 3.—South-facing cliff on the north side of Whitehaven Bay, S.E. Barbados. About 60 feet high. Oc. Oceanic chalks nodular in places. Resting on and against this is the hard platy limestone of the basal coral-rock with *Haliotis, Pleurotomaria,* etc. At the junction is a remanié bed. The basal bed passes up imperceptibly into ordinary massive coral-rock C.C. At S the basal lithothamnial bed dies away and the coral-rock becomes marly and mixed with Oceanic chalk. A variety of the large *Strombus gigas* and a few Amphisteginae occurred here.

Hopefield and Loamfield.

An anticlinal inlier of Oceanic chalks, a half to three-quarters of a mile across, occurs here ; the material is much broken up at the surface, but borings for oil show it to be 700–800 feet thick. At the junction there is a marly bed of phosphatic and clay ironstone nodules 1–2 feet thick ; on the south-west side of the inlier the basal coral-rock dips about 23° off the Oceanics and passes up into old massive coral-rock. Fossils include Bivalves, *Haliotis,* well-preserved Terebratulids, and a few *Amphisteginae.*

Bagatelle or Parkham Park.

Here a north–south fault causes a strip of Oceanics to be exposed as an inlier among coral-rock. Pieces of the *Amphistegina* bed can be collected, but neither the junction nor the basal bed is well seen. Just west of this, Dr. Huber, who traced this fault, tells me that the coral-rock is proved by a boring to be 240 feet thick. It is 260 feet thick at Montcrieff and 250 feet at Government Hill, this being about its maximum known thickness.

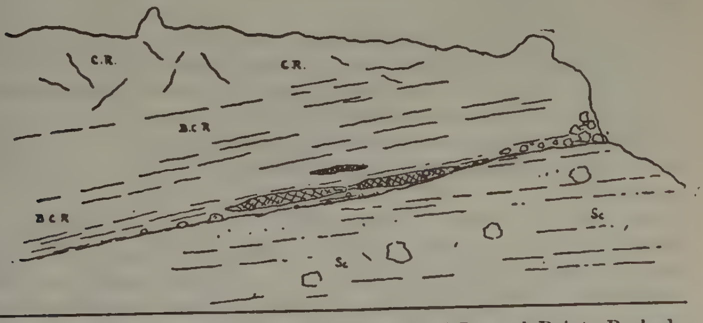
THE SCOTLAND AREA.

It is rather remarkable that Mount Hillaby, the highest point of the island, should be composed of Oceanic chalks and not of coral-rock. This leads to the question whether possibly some of the softer beds of the denuded area, Oceanics, Joe's River Clay, or softer Scotlands may have risen or been squeezed upwards after removal of the weight of the coral-rock. Oceanics and Scotland beds, and possibly some coral-rock, are to some extent folded and involved east of and below Bissex Hill. Dr. Huber is investigating this problem, and the question arises whether this complication is or is not a tectonic feature resulting from lateral thrust during the uplift of the island.

It is also a debatable question whether the masses of coral-rock one sees on the Scotland slopes are all slipped or not. One considerable mass east of Bissex Hill has the basal bed apparently undisturbed at the bottom and may be in its original place of deposition.

A POSSIBLE MODE OF ORIGIN OF "EXOTIC BLOCKS".

Numerous masses of coral-rock have rolled down the slope of the Scotland beds from the high escarpment of the "travelling" anticline to the sea 900 feet below and lie on the shore near Bathsheba. Some of them are already nearly submerged and may travel still farther down the submarine slope and become embedded in mud accumulating at the present day. If one can imagine the coral-rock covering of the island to be later entirely denuded away and the sea bed in the future to be raised up as a geological formation one would find these masses presumably in the position of "exotic blocks".



TEXT-FIG. 4.—Cliff section in Spring Bay south of Ragged Point, Barbados. Height 88 feet. Sc. Scotland sandstones dipping 45° N. B.C.R. Basal coral-rock with *Haliotis*, etc., near the base. C.R. Massive Pleistocene coral-rock. Cross hatched portions indicate caves near the junction filled with greenish clay and phosphatized limestone fragments containing reptile (Iguana) bones.

Probably the large masses and stacks of Cretaceous limestone embedded in the Lower Eocene[1] marls at Point-a-Pierre and other places on the north side of the central range of Trinidad originated in some such manner by becoming disengaged from ancient overthrust cliffs.

BISSEX HILL. (B. on map.)

This locality has been often described especially by Harrison and Jukes-Browne, who give a section across the hill indicating several faults; but in reality the site is much more obscure than one might gather from their sketch. There is no coral-rock on the top, but the curious limestone that caps the hill has been traced in other districts and seems to be a final development of the Oceanic beds. It seems unlikely that we have here a passage to coral-rock conditions, as has several times been suggested. The limestone on the hill seems to merge down into Oceanic chalks and these in turn rest unconformably on the oil-soaked sands called the Joe's River Clay.

One may hope that the Oceanics may eventually yield some large identifiable fossils. The record of *Cystechinus crassus* Greg.[2] from 166 feet depth at Haynesfield does not make it certain whether it is from some beds associated with the base of the coral-rock or with true Oceanics.

The position of the bed of silicified limestone that yielded *Scalaria ehrenbergi* Forbes has never been definitely ascertained. It is said to be from near the top of Bissex Hill, but no such bed is known there, and it may be from some bed lower down to the east now covered up. The marly clastic fragmental limestone on top of the hill has some bivalves and Terebratulids in it but all very poorly preserved.

One also finds errant or scrawl-like worm tubules; calcareous algæ; Bryozoa, at Consett cutting; Echinoderm tests and spines; corals of small or simple character, generally crushed or badly preserved; *Callianassa* claws, at Cluffs; Shark's teeth, generally small; and among the foraminifera, *Amphistegina lessoni*; and *Cuneolina*, at Consett cutting, rare.

DESCRIPTIONS OF FOSSILS.

Haliotis (*Padollus*) *barbadensis* sp. nov. Pl. XII, figs. 1–5.

The largest well-preserved specimen is 30 mm. long, 21 mm. wide, and 12 mm. high; other imperfect examples are rather larger. Outline rounded to oval, shell of four whorls, spire small but elevated, sutures well marked. The body whorl has about sixteen holes

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[1] M. E. Lehner, "Introd. à la géologie de Trinidad," *Annales de l'Office des Combustibles lignites*, No. 4, Paris, 1935, 695.

[2] *Quart. Journ. Geol. Soc.*, xlv, 1889, 641.

BASAL CORAL-ROCK FOSSILS, BARBADOS.

	Cluffs.	Crab Hill.	Spring Hall.	Gay's Cove (S. end).	Cherry Tree Hill.	Caledonia (1,050 ft.).	Chimborazo (1,090 ft.).	Consett Point.	Whitehaven.	Ragged Point.	Loamfield and Hopefield.	Fortress Hill (foot of).	Main Coral-rock.	Living Species.
GASTEROPODA.														
Haliotis barbadensis sp. nov.	+		+	+		+			+	+	+			
Pleurotomaria cf. *quoyana* Fischer									+					?
Fissurella (*Glyphis*) sp. .									+				?	?
Hipponyx sp. . . .							+						?	?
Conus cf. *limonensis* Ollson .									+					
Cerithium litteratum Born .									+				+	+
Oliva sp.								+	+					?
Olivella sp.												+		?
Murex sp.									+					?
Astralium sp. . . .									+			+		
Turbo cf. *saltus* Ollson .	+	+	+			+	+		+	+				
Monodonta (?) sp. . .									+					
Calliostoma cf. *zonamestum* Ad.									+					?
Rissoina sp. . . .									+					
Obeliscus cf. *dolabratus* Linn. .									+				+	+
PTEROPODA.														
Cavolina sp. . . .	+									+	+			?
Diacria sp. . . .	+									+	+			?
Cleodora (?) sp. . . .	+									+	+			?
LAMELLIBRANCHIATA.														
Ostrea cf. *frons* Linn. . .					+			+					+	+
Modiola cinnamomeus Chem.	+		+			+	+		+	+	+		+	+
Barbatia sp. . . .			+									+		
Pectunculus sp. . . .					+	+		+					?	?
Pecten cf. *pittieri* Dall . .								+		?		+		
,, cf. *cercadica* Maury. .								+						
,, *gibbus*-forms . .								+						
Spondylus bostrychites Guppy								+						
Chama sp. . . .						+							?	?
Lima scabra Born . .									+				+	+
Meiocardia cf. *agassizi* Dall .	+	+	+		+	+	+		+	+	+			+
Cardium spp. . . .								+			+		?	?
Antigona sp. . . .	+		+			+			+		+	+		
Periploma sp. . . .	+													
Diplodonta cf. *turgida* Verrill									+					?
Gastrochaena rostrata Spengl. .	+	+					+		+				+	+
BRACHIOPODA														
Liothyrina or *Gryphus* spp. .	+		+			+	+		+	+	+			+
Terebratulina caput-serpentis Linn.									+					+
Megathyris decollata Chem. .										+				+

the last four or five of them open, the upper surface is well arched, the last whorl with a noticeable groove and a ridge bounding it on the outside situated about the middle of the distance between the suture and the line of holes. This surface carries several broad undulating radiating ribs which widen towards the medial groove where they are interrupted but continue beyond it as irregular elevations. They are crossed by numerous fine elevated wavy thread-like ridges; outside the line of holes the shell surface is hollowed and slopes outwards, the sunken space carries six to seven spiral, rather fine, wavy and irregular ribs. The lower outer margin is thickened or ridged and below it the shell is strongly bent under to form a wide and strong inner lip or columellar flattened plate.

Locality.—Basal beds of the coral-rock, several localities in Barbados. The peculiar features of this species are the elevated spire and the very strongly reverted thick inner lip or columella. These make it more spiral and less limpet-like than most of the living species of *Haliotis*.

I was very surprised to find a *Haliotis* in Barbados, being well aware that no living species of that genus is known on the coasts of the east side of America or the Antillean region. However, a deep water form, *H. pourtalesii* Dall, was dredged near Florida reefs in 1869 in 200 fathoms of water. The original specimen was destroyed in the Chicago Exhibition fire in 1871 but a species described as the same was dredged from 33 fathoms near Charles Island of the Galapagos Group.

Haliotis pourtalesii is illustrated in Tryon's *Manual* (vol. xii, pl. 22, figs. 7 and 8), and the general shape and size of the Barbados fossil is certainly similar, being rather rounded in outline with a high spire and steep slope below the line of holes. The thread-like raised lines also look similar, but the recent *H. pourtalesii* has a much stronger raised ridge about midway between the suture and the line of holes.

The nearest relative to *H. pourtalesii* is said to be *H. parva* Linn. of South Africa, but that species is more elongated and has a much more prominent median rib. The surface ornamentation of *H. parva* is rather similar to that of the Barbados fossil, but in *H. parva* the riblets are more closely set and broader and the inner lip underneath is much thinner and less prominent.

The earliest *Haliotis* is said to occur in the highest chalk of Maestricht. A rather large and elongated Miocene form, *H. volhinica* Eichw., is found in the Upper Coralline Limestone of Malta; a new species, *H. elsmerensis*, Vokes, has recently been described from the Pliocene of S. California; Dall says the genus is so far unrepresented in the Florida Pliocene. The present-day centre of distribution of the genus is Australia and adjacent seas where the greatest number and diversity of forms occurs. None occur on the west coast of America south of Lower California, nor on the shores of the east side of America or the West Indies.

Pleurotomaria cf. *quoyana* Fischer and Bernardi. Pl. XII, Fig. 6.

A cast of six or seven whorls 16 mm. high and the same in diameter is evidently a portion of a spire of *Pleurotomaria*. The sides are appreciably concave, the sutures faint and indistinct, the slit band with its backwardly curving lunular growth lines lies about half-way between the sutures; below and above it are several faint spiral thread-like incised lines irregularly spaced and these are crossed by faint regular backwardly curving ridges. The later whorls and base are missing.

Locality.—Whitehaven, one cast in a hard platy limestone. The position of the slit band, etc., agrees with that on the living *P. quoyana*, F and B, which Dall quotes as 42 mm. in height and diameter and having a depth range of 73–130 fathoms extending from Guadeloupe to Barbados. Only two specimens seem to be known; the type in the collection of Mr. De Burgh and another in the Mus. Zool., Camb., Mass. Mr. H. Fulton tells me he has heard of no more records of it.

P. adansoniana, Crosse and Fischer, is a much larger species but is rather less rare; the type being in the collection of M. H. Crosse, of Paris. The recent *Pleurotomaria* is the *rara avis* of the conchologist; in 1921 I bought a *P. adansoniana* in Barbados, dredged from 5 miles south-west of Bridgetown at a depth of about 350 feet, for £30, "to keep it from going to America." This specimen is now exhibited in the British Museum (Natural History) among Lias *Pleurotomariae*. The well-known giant specimen from off Tobago shown in the shell gallery in the same museum, is, or was, valued I believe at £100.

Conus cf. *limonensis* Ollson. Pl. XII, fig. 7.

A cast of a smooth slender cone shell in hard platy limestone at Whitehaven is probably this species of the Costa Rica Miocene. (*Bull. Amer. Pal.*, No. 39, 9, Part 1, 1922, 47, pl. 3, figs. 7 and 8.)

Murex sp. Pl. XII, fig. 8.

A gelatine cast of a small, thin-shelled *Murex*, 22 mm. long and 14 mm. wide, has five to six whorls which enlarge rapidly and have wide and deep sutures. The main varices are narrow and not very prominent and between them there are three obscure minor varices crossed by four or five spiral ribs; the anterior portion has been elongated.

This is a form with widely separated whorls, it is not perfect enough to give a species name to, but it recalls the recent *M. beaui* Petit, a rare, deep-water species from 117 fathoms off Guadeloupe; but in the Barbados fossil the whorls enlarge more rapidly. A species more like it was found in the Miocene tuffs of Carriacou[1] but has the earlier whorls very badly preserved.

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[1] Geol. Mag., LXXII, 1935, 541, pl. xxi, fig. 3.

Turbo sp. Pl. XII, Figs. 13 and 14.

Shell rather thin, of five whorls, which are well rounded and separated by deep and rather canaliculate sutures. Umbilicus not perforate, with a faint callosity, aperture nearly circular. Early whorls have two spiral ridges, the body whorl has about nine irregularly spaced spiral lirae with smaller thread-like raised lines between them; the spiral ribs are not noded. Height 16 mm., width 16 mm.

Casts of this *Littorina-like* Turbinid shell are rather common in the basal bed; being only casts and moulds no definite species name can be given, but they are rather like *T. saltus*, Ollson[1] of the Costa Rica Miocene.

PTEROPODA.

Pteropoda occur in the basal rock at Cluffs, Ragged Point, etc., but are rare and badly preserved.

Diacria sp., a dorsal part.

Cavolina sp., a cast, the dorsal part flattened, with three broad well-defined radiating flattened ridges; ventral part very inflated anteriorly; 7 mm. wide, 5·5 mm. thick, apparently unlike living forms.

Cleodora (?) sp.

Barbatia sp. Pl. XII, figs. 20 and 21.

Casts up to 22 mm. long and 11 mm. high with very strongly reticulate surface ornamentation are too imperfect to identify but the decoration resembles that on *B. domingensis* Lam. from Miocene beds.

Pecten cf. *pittieri* Dall. Pl. XII, fig. 23.

Fragments, minus the apex and ears, of a very large *Pecteu* which must have been about 160 mm. or 6¼ inches in diameter, were collected near the base of the old coral-sand rock in the Consett railway cutting. The surface has had about ten prominent broad radiating ribs with obscure nodose swellings, separated by broad interspaces; both ribs and sulci widen as the valve increases in size. The ribs carry five or six rather close-set smaller ribs and the sulci have three or four more widely spaced and irregular ribs. The surface becomes scaly with foliaceous growth lines towards the margins.

It agrees fairly well with a valve of *P. pittieri* from the Oligocene of Yumuri River, Cuba, figured by C. W. Cooke,[2] but the Barbados specimen being larger, the interspaces have become as wide as the ribs.

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[1] *Bull. Amer. Pal.*, No. 39, ix, 1922, 161, pl. 15, fig. 12.

[2] "Contrib. to Geol. and Pal. of West Indies," *Carnegie Inst. of Washington*, p. 135, pl. 13, fig. 5.

A smaller specimen of a nodose *Pecten* which may be this species was collected by Dr. Huber in the lower coral-rock beds at Ragged Point. Sir J. B. Harrison in a letter to me mentioned a large well-preserved *Pecten*, much larger than the living *P. nodosus* which he obtained from the base of the coral-rock in Barbados, but without specifying the locality. I am indebted, however, to Mr. R. H. Emtage, estate owner and dealer in manjak or glance pitch in Barbados, for the information that it was he who found this *Pecten* at the foot of Fortress Hill at an altitude of about 750 feet and gave it to Professor Harrison, who regarded it as supporting his view that the older fossils occur at the higher levels or terraces. In reality it tends to disprove rather than to prove Harrison's theory because a fault occurs here which exposes the base of the coral-rock and the *Amphistegina* bed, resting on Oceanic chalks. I found here a fragment of one of these very large extinct *Pectens*, but they are rare and difficult to come by.

Pecten cf. *cercadica* Maury, var. Pl. XII, fig. 24.

At Consett cutting *Pectens* occur with fan-shaped valves, moderately inflated, carrying eighteen radial ribs widening rapidly with narrower interspaces. The interspaces have fine sharp growth lines which become weaker on the ribs. The ears are nearly equal in size and have three or four ribs near the base and sharp growth lines. These valves, the largest of which is 40 mm. wide and 37 mm. high, resemble the above species from the island of Santo Domingo. (*Amer. Bull. Pal.*, No. 29, 5, 1917, 188, pl. 34, fig. 11.)

Pectens allied to *P. gibbus* Linn. or *P. circularis* Sow.
Pl. XII, figs. 25 and 26.

Several *gibbus Pectens* are found in Consett cutting; they are always separated valves, but probably more or less equivalve. One (Fig. 26) is well inflated, has seventeen to eighteen flat-topped rather overhanging ribs with deep narrow interspaces which carry sharp growth lines The ears are sub-equal, well cut out, and have near the base three radial ribs.

Another valve (Fig. 25), more circular and more regularly inflated, has twenty-four smooth radial ribs, well rounded, with narrower rounded smooth interspaces; the ears are small and subequal.

It seems useless to give any new names to these *Pecten* valves but they resemble more or less various Venezuelan and Caribbean forms figured by F. Hodson and G. D. Harris[1] as subspecies of *P. circularis* Sow. a living Pacific coast form. They may compare also with *P. compactus* Dall[2] of the Pliocene of Ventura Co., California.

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[1] *Bull. Amer. Pal.*, No. 49, 13, 1927, 25, pls. 14–15.

[2] *Tert. Fauna Florida*, iii, part 4, 1898, 707, pl. 34, fig. 5.

Meiocardia cf. *agassizi* Dall. Pl. XII, figs. 15, 16, and 17.

Shell rather inflated, beaks small and incurved, situated about the anterior fourth of the valve; a blunt curving angulation passes from behind the beak to the lower posterior edge. In front the surface is rounded and smooth except for very fine growth lines and slight undulations; behind the ridge the surface carries a fainter ridge rather anterior of the middle and the surface is ornamented by faint close-set sharp growth lines. A narrow escutcheon also faintly striated borders the junction of the valves behind the beak. Length 20 mm., height 18 mm., depth of one valve 10 mm. The above species, to which this rather common basal coral-rock fossil seems to belong, is recorded as occurring in the West Indies and having a range in depth of 117 fathoms.[1]

Antigona sp. Pl. XII, fig. 18.

Casts with sharp concentric ribs may be *P. acuticostata* Gabb., figured by Maury among Dominican fossils. They are apparently not the living species *A. rugosa* Gmelin.

Liothyrina or Gryphus. Pl. XII, figs. 27 and 28.

Terebratulids occur at the base of the coral rock at several localities. They vary in shape and size but probably all belong to one or to two closely allied species such as the recent *T. cubensis* Dall; *T. bartletti* Dall; and the newly described *T.* (*Gryphus*) *bartschi* Cooper.[2] They all have the beak and foramen of the ventral valve closely incurved against the beak of the other valve, but not bent over it, a well truncated foramen, the shell thickened in the foraminal region, and the test finely punctate.

A large specimen is 43 mm. long, 32 mm. wide and both valves together are 25 mm. thick; and resembles figures of *G. bartschi* but the anterior commissure is more sinuous and the shell widens more anteriorly, suggesting rather the shape of *G. cubensis*. It resembles specimens from the Manchioneal beds of Jamaica (Lower Pliocene ?) which are comparable with *G. cubensis*. [3] Other specimens are smaller; two individuals found close together vary considerably in relative width and length, but are probably only variants of one species.

Terebratulina caput serpentis, Linn. Pl. XII, fig. 29.

A specimen from Whitehaven 8 mm. long, 5 mm. wide and 4 mm. thick agrees approximately with this species. The dorsal valve has about twenty-four radiating outwardly curving ribs.

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[1] *Bull. U.S. Nat. Mus.*, No. 37, 1889, p. 54, pl. 40, fig. 7.

[2] New Brachiopods, *Smithsonian Miscell. Coll.*, 91. No. 10, 1934, 1, pl. i, figs. 1–8.

[3] GEOL. MAG., LXVII, 1930, 213, pl. 12, figs. 1 and 2.

Megathyris decollata Chem. Pl. XII, fig. 30.

Ventral valve deep, area as wide as the valves, high and concave with a wide open foramen; dorsal valve nearly flat with ten broad radiating ribs, coarsely punctate. Width 5 mm., length 4 mm., thickness of valves 2·5 mm.

Locality.—Ragged Point, one specimen.

It resembles specimens of the recent form from Madeira in the British Museum Collection; these vary considerably, some having the dorsal valve nearly flat, others convex, and the ribs vary in prominence.

DESCRIPTION OF THE POST-CORAL-ROCK BEDS.[1]

The coral-rock being a formation of such recent origin, it might be surmised that the later beds would not attain any great thickness, and indeed it is only in one part of the island, the portion of coast between Ragged Point and Whitehaven, where they attain any thickness or importance as a formation. Elsewhere they are more or less a coastal veneer of calcareous sand-rock around the southerly more recently emerged anticlines of the island.

The fossils are land and marine mollusca which occur mingled together. The land shells comprise about three species, identical with or slight varieties of existing forms:—

(1) *Helix* (*Caprinus*) *isabella*, Fér. Thick-lipped and more solid than the usual living form.

(2) *Bulimulus*, near *guadaloupensis* Brug. The fossils vary a good deal.

(3) *Helicina barbadensis*, Pfr. The fossil is larger and more solid than the living shell. The marine assemblage is more like the series found around the coast at the present day than it is to the coral-rock fauna.

The following are some of the marine fossils of the post-coral-rock beds:—

Chiton plates.
Acmaea cubensis, Reeve.
Fissurella barbadensis, Gmel.
Hipponyx antiquatus, Linn.
Coralliophila cf. *galea*, Chem.
Coralliophila nivea, C. B. Ad.
Triton tritonis, Linn.
Ranella (*bursa*) *thomae*, D'Orb.
Phos pallidus, Powis

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[1] The only previous reference to these beds I can find is Jukes-Browne and Harrison, *Quart. Journ. Geol. Soc.*, xlvii, 1891, 217, where small corals and land shells are mentioned from Culpepper Island.

Astralium caelatura, Chem.
Tectarius nodulosus, Gmel.
Bulla maculosa, Mart.
Arca imbricata, Brug.
Asaphis coccineus, Mart.
Cardium spp.

Hastings.

Near Hastings, half a mile east of Needham Point Lighthouse below the old fort and 15–20 feet above sea-level the sloping terrace of coral-rock is covered by a bed of rolled pebbles overlain by hard, calcareous sand-rock, the whole being about 1½ feet thick and dipping 15° seawards. Fossils include *Helix isabella*, *Helicina*, and a few marine forms.

Hastings to St. Lawrence.

At the foot of the second terrace behind the Marine Hotel about 85 feet above sea-level the lower slope is occupied by a bed some 15 feet thick, banked up against an eroded surface of coral-rock and dipping 25° seawards. It consists of well-bedded white or pink marls mixed with debris of coral-rock; a few marine fossils and many land shells of the three species already mentioned occur.

Southwards the same terrace sinks to a lower level, and forms a line of curving wave-cut cliffs and at St. Lawrence the same bed reappears at 35–40 feet altitude. Here the base of the cliff is veneered by a bed 5–7 feet thick, dipping seawards, consisting of a calcareous sand-rock covered by a marly bed with *Livonia pica*, etc., and the usual land shells.

At Dayrell's Road on the first rise above the sea at about 20 feet altitude a bed some 5 feet thick occurs, and consists of a jumble of large and small rounded masses of coral-rock. A large *Strombus* and smaller marine species were seen in it but no land shells.

South Point Anticline.

Post-coral-rock veneers occur here along the south-east side of Oistin Bay; on the beach near South Point Lighthouse, and ¼ mile north-east of Silversands in Long Bay. In Oistin Bay the beds are about 3 feet thick and consist of rounded coral pebbles and pink and white marls passing up to a height of about 20 feet. Well preserved *Helix* and *Helicina* occur, mixed together with numerous marine forms.

On the shore south of the lighthouse a brownish bed with *Helix* and *Helicina* forms a veneer about a foot thick on the coral-rock, up to about 5 feet above sea-level. Near Silversands it is about 2 feet thick and overlies the coral-rock, and yields a well-preserved series of fossils: *Pagodus*, *Coralliophila*, *Vermetus*, *Chiton* plates, etc.

Harrismith (*2 miles south of Ragged Point*).

A feature here points to the comparatively recent uplift of this part of the island. A large block of coral-rock, more or less square in shape, 10 feet high and 15 feet long rests on a sort of pedestal about 9 inches high which has a calcreted surface under the block; the mass is upside down the corals in it being inverted. All the other material that may have surrounded it has been removed and the surface of the coral-rock on which it rests has been lowered by 9 inches or a foot. It lies on top of the cliff about 100 feet from the edge and must have been washed up a slope before the cutting of the present cliff which is about 45 feet high. Its size seems to have protected it from solution. Even a West Indian hurricane can scarcely have thrown a mass this size up a vertical cliff 40 feet high.

Whitehaven and Culpepper Bay.

Culpepper Bay, three-quarters of a mile west of Ragged Point, is a picturesque cove that has been eroded by the sea. Its base is formed of Scotland sandstones overlain on the north-west towards Whitehaven by Oceanic chalks above which follows a line of cliffs of basal coral-rock bounding the bay on that side. Most of Culpepper Bay and Skeete's Bay up to and in front of the residential house is filled with post-coral-rock beds rising to about 40 feet in height, the sequence being as follows:—

		Feet.
A.	Loosely consolidated whitish nodular marl with land shells, *Helix*, *Bulimulus*, etc.; probably reassorted Oceanic chalks, dipping seawards about 15°, forming small cliffs on both sides of Culpepper Bay	10–12
B.	Consolidated calcareous sand-rock with bands of pebbles of limestone and coral and layers of water-worn marine shells mostly with colour markings. This bed persists to about 35 feet altitude nearly to the house and weathers into low ragged hardened sea cliffs	25

Culpepper Island which lies in the bay about 100 yards from the land is also formed of this sequence of beds, showing that these post-coral-rock beds have already undergone marine erosion after the last coastal uplift and are by no means quite recent in age.

Reptile (*Iguana*) *Bed near Ragged Point.* Fig. 4.

In Spring Bay, south of Ragged Point, about 30 feet up the cliff, which is 88 feet high, are three or more elongated cavities in the rock at or near where the basal coral-rock rests on the Scotland sandstones. They are filled with green or brown clay which contains numerous reptile bones and some lumps of phosphatized limestone; and were apparently first noticed by Mr. M. H. Watson, who keeps a rest-house on the cliff top; and he and Dr. Huber and I have collected from the bed. Besides the Iguana bones Dr. Huber obtained jaws of a small rodent.

The clay is evidently post-coral-rock in age, but is not recent, and resembles some of the very mature soils one sees at high levels. It was probably washed in or the reptiles had access to the small caves from some part of the cliff now fallen away, and the suggestion is that this part of the island extended further out to sea in fairly recent times.

SUMMARY.

1. The coral-rock commences nearly everywhere with a basal bed of varying thickness containing a fauna of pre-Pleistocene aspect among which the genus *Haliotis* (absent from these coasts at the present day), *Pleurotomaria*, *Meiocardia*, etc., are noticeable. This faunule may have lived at a depth of 700–1,000 feet.

2. The supposition that the southerly anticlines are a later uplift than the main portion of Barbados is supported by the absence of ravines, and the presence of post-coral-rock beds which occur as coastal veneers at low altitudes, and in greater thickness in the south-east corner near Whitehaven.

3. The south-east part of the island from Consett Point to Ragged Point has probably extended further seawards in comparatively recent times; the series of converging faults and dislocations in the cliff sections suggest that the thrusts from the west or south-west may have been resisted by this part of the island.

4. The relative claims of fault-scarping or marine erosion in production of the rising terraces is discussed; and new information regarding the thickness of the coral-rock at sea-level from a boring is detailed.

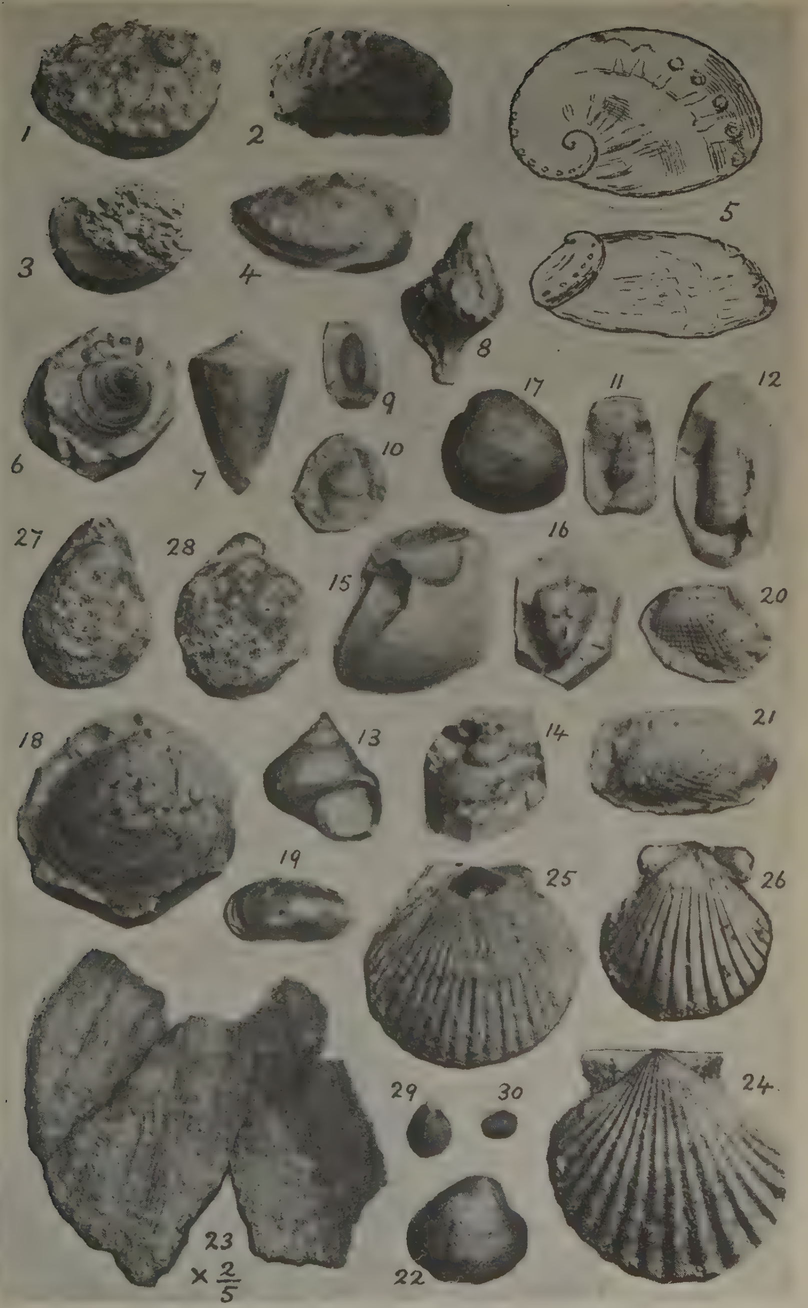
5. The finding of a faunule with Pliocene or possibly Miocene affinities at the base of the coral-rock puts the Oceanic series further back, into the Miocene.

EXPLANATION OF PLATE XII.

(All except Fig. 23 are approximately natural size.)

FIG.

1. *Haliotis barbadensis* sp. nov. Whitehaven.
2. —— A rather distorted specimen. Ragged Point.
3. —— An underside showing the large columellar plate. Ragged Point.
4. —— Gelatine impression of a cast of part of edge and apex. Whitehaven.
5. —— Restored sketches of a larger specimen, showing outline and elevation of the spire. Spring Hall.
6. *Pleurotomaria* cf. *quoyana* Fischer. Impression of an apex. Whitehaven.
7. *Conus* cf. *limonensis* Ollson. An impression. Whitehaven.
8. *Murex* sp. An impression. Whitehaven.
9. *Olivella* sp. An impression. Foot of Fortress Hill.
10. *Monodonta* (?) sp. An impression. Whitehaven.
11. *Rissoina* sp. An impression. Whitehaven.



BASAL CORAL ROCK FOSSILS. BARBADOS.

[*To face p.* 358.

FIG.
12. *Obeliscus* cf. *dolabratus* Linn. An impression. Whitehaven.
13. *Turbo* cf. *saltus* Ollson. An impression. Crab Hill.
14. —— An impression. Caledonia.
15. *Meiocardia* cf. *agassizi* Dall. An impression. Whitehaven.
16. —— Impression of anterior end of conjoined valves. Whitehaven.
17. —— A natural cast of left valve. Crab Hill.
18. *Antigona* sp. Impression of a right valve. Spring Hall.
19. *Modiola cinnamomeus* Chem. Whitehaven.
20. *Barbatia* sp., a coarsely reticulate form. An impression. Spring Hall.
21. —— Impression of another specimen. Foot of Fortress Hill.
22. *Diplodonta* cf. *turgida* Verrill. Whitehaven.
23. *Pecten* cf. *pittieri* Dall. Fragments of a specimen, about two-fifths natural size, base of section at Consett railway cutting.
24. *Pecten* cf. *cercadica* Maury. Same locality.
25. *Pecten* sp. a *gibbus*-like species. Same locality.
26. *Pecten* sp. A different species of a *gibbus*-like type. Same locality.
27. *Liothyrina* or *Gryphus* sp. Hopefield.
28. —— Another specimen. Same locality.
29. *Terebratulina caput-serpentis* Linn. Whitehaven.
30. *Megathyris decollata* Chem. Ragged Point.

Note on a Pegmatitic Hornblende from the Carsphairn Complex

By W. A. DEER.

A NUMBER of small pegmatitic patches occur in the development of the later stages of the hornblende hybrids of the Cairnsmore of Carsphairn Complex.[1] These are best seen on the eastern side of the Gairy of Cairnsmore, and it is within these pockets of late residuum crystallization that this hornblende occurs. The pegmatites consist of milky quartz, greenish-black hornblende and a clove coloured sphene. The two latter minerals develop idiomorphic crystals. The hornblende, though usually only ½ inch in length, occasionally grows to 1½ inches long in slender prismatic crystals showing the faces (100), (110), $(1\bar{1}0)$, (130), $(1\bar{3}0)$, (010), $(0\bar{1}1)$, and (011).

Its optical properties are :—

$(-)\ 2V = 79^\circ \pm 2^\circ$
$\gamma = 1{\cdot}680 \pm {\cdot}002$
refractive indices $\beta = 1{\cdot}669$
$\alpha = 1{\cdot}659$
γ = yellow brown
pleochroism β = pale yellow brown
α = pale yellow
$Z \wedge c = 24^\circ$ dispersion $v > \rho$

The analysis of the hornblende is given below and compared with some typical common hornblendes from granites and syenites. The main feature of the analysis is the high silica and low alumina, and in this characteristic it compares well with the analysed hornblendes from granites. In combination with this high ratio of silica to alumina the mineral has a high iron content, and in this compares well with many hornblendes from both granitic and syenitic rocks. The alkaline nature of the latter is reflected in a higher percentage of alumina and alkalies within the amphibole molecule of the common hornblendes occurring in these rocks. These features of this late forming hornblende are consistent with the concentration of silica and iron in the late magmatic residuum, and providing the amphibole structure can be maintained these oxides will be fully incorporated into the hornblende molecule. The slight titaniferous nature of the hornblende and the idiomorphic development of the sphere indicates the stability of the latter under late magmatic conditions.

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[1] Deer, W. A., "The Cairnsmore of Carsphairn Igneous Complex," *Quart. Journ. Geol. Soc.*, 91, 1935, 47–76.

	1.	2.	3.	4.	5.
SiO_2 .	50·18	51·69	48·55	43·08	43·02
Al_2O_3 .	4·27	4·17	5·71	11·41	11·94
Fe_2O_3 .	2·78	2·34	2·41	4·74	4·58
FeO .	14·18	9·83	10·56	11·42	13·08
MgO .	11·75	17·17	14·76	12·41	11·36
CaO .	11·84	12·17	13·73	11·61	11·08
Na_2O .	0·95	0·82	1·88	1·98	1·65
K_2O .	0·51	0·79	0·81	1·23	1·20
$H_2O +$.	1·93	1·13	0·91	1·64	2·12
$H_2O -$.	0·20				
TiO_2 .	1·58	0·14	0·27	0·90	0·45
MnO .	0·30	—	0·15	—	—
P_2O_5 .	*nil*	—	0·06	—	—
	100·47	100·25	99·80	100·42	100·48

1.—Green hornblende. East of Cairnsmore Gairy, Carsphairn. (Analyst W. A. Deer.)

2.—Brown hornblende from amphibole granite. Pré de Fanchon Vosges. Rosenbusch: *Elemente*, 1898, 73. (Quoted from Johannsen, *Petrography*, 159.)

3.—Average of a number of analyses of various hornblendes from granites. Tschirwinsky. (Review in *Neues Jahrb.*, 1913, 11, 240.)

4.—Green hornblende from syenite. Plauen.

5.—Green hornblende from syenite. Arendal. (Analyses 4 and 5 are quoted from Kunitz, *Neues Jahrb., B.B.* 60, 1930, 245.)

The analysis has been calculated on the basis of 24 oxygen atoms to the unit cell,[1] and the result is tabled below, p. 361.

The amount of aluminium replacing silicon in the Carsphairn hornblende is 0·64. According to Warren's table [2] this degree of replacement should be accompanied by an increase in the value of x group to approximately 2·25 due to the partial filling of the vacant AA [1] positions in the tremolite structure,[3] in order to balance

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[1] Warren, B. E., "The crystal structure and chemical composition of the monoclinic amphiboles," *Zeits. Kryst.*, 72, 1930, 493–517.

[2] Warren, op. cit., 512.

[3] Warren, B. E., "The Structure of Tremolite $H_2Ca_2Mg_5(SiO_3)_8$," *Zeits. Kryst.*, 72, 1929, 42–57.

	Wt. %	*No. of metal atoms on basis* (24(OOH.F.)			*Group.*
SiO_2	50·18	7·360		8·00	z
Al_2O_3	4·27	·740	0·640		
			0·100	4·95	y
TiO_2	1·58	·182			
Fe_2O_3	2·78	·308			
MgO	11·75	2·577			
FeO	14·18	1·746			
MnO	0·35	·037			
Na_2O	0·95	·271		2·23	x
CaO	11·84	1·866			
K_2O	0·51	·093			
H_2O+	1·93	1·895		1·90	
H_2O-	0·20	—			
	100·47				

This gives the formula

$$(OH)_{1\cdot9}\ (Na, Ca, K)_{2\cdot2}\ (Mg, Fe'', Fe''', Ti, Mn, Al)_5\ [(SiAl)_8O_{22}]$$

the excess negative valency. The replacement of silicon by aluminium is also balanced by the replacement of divalent magnesium by trivalent aluminium and iron and tetravalent titanium. In the above analysis the total excess electro-negative valence due to the replacement of Si^{++++} by Al^{+++} and Ca^{++} by Na^+ and K^+ is 0·77 and the total excess electro-positive valence due to the replacement of Mg^{++} by Al^{+++}, Fe^{+++}, and Ti^{++++} is 1·00.

The Marginal Rocks of the Cairnsmore of Carsphairn Complex.

By W. A. Deer.

Introduction.

THE marginal rocks of this intrusion were described briefly in a paper dealing with the Cairnsmore complex.[1] The intrusion is composite, consisting of a central granite, and successive zones of acid hybrid, tonalite, and basic hybrid. The complex began with the intrusion of gabbro, and when crystallized, but still at a high temperature, it was followed by the tonalite with the production of the basic hybrids. The original basic intrusion is nowhere found in an unaltered condition but is now represented by the "dioritic" lenses. It is seen then that the outermost zone of the intrusion uncontaminated by the incorporation of the sedimentary country rocks is itself a hybrid resulting from the intrusion of tonalite in the original gabbro. In the earlier paper it was suggested that the

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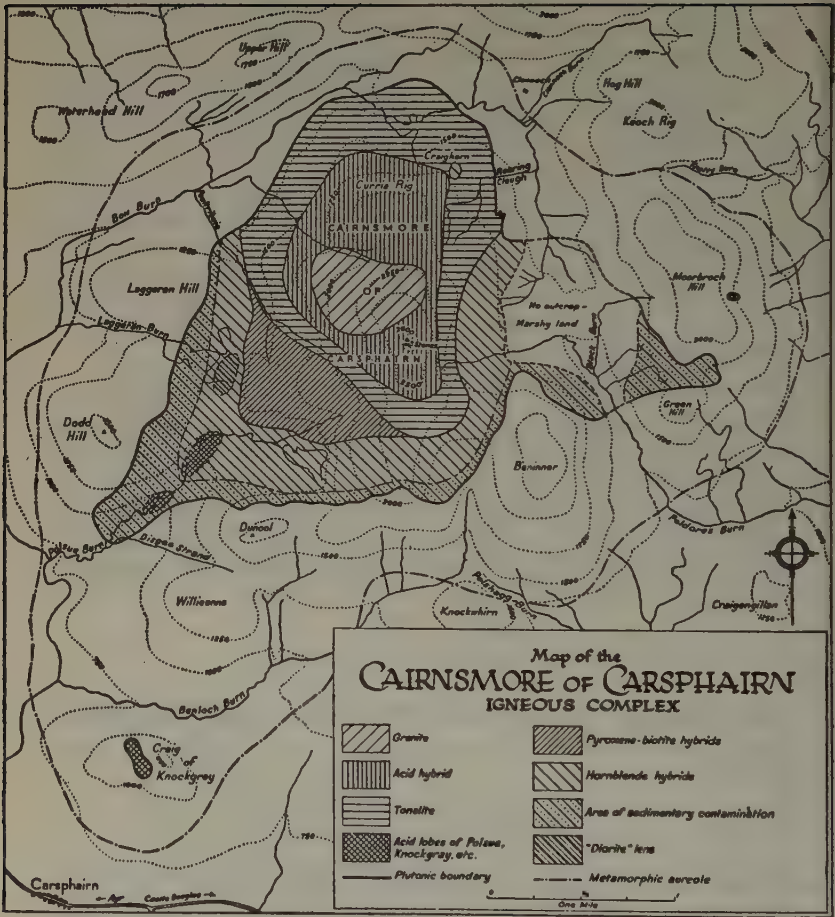
[1] Deer, W. A., *Quart. Journ. Geol. Soc.*, xci, 1935, 62.



character of these marginal rocks was due to the combined effects of sedimentary contamination and igneous hybridization.

The sediments around the intrusion are conglomerates and pebbly grits, blue greywackes, blue flags, and dark shales included in the Arenig, Glenkiln, and Hartfell series. A few calcareous shales also occur but are relatively unimportant. Within the metamorphic aureole these sediments form a somewhat uninteresting series of hornfelses included in Tilley's[1] non-calcareous shale division and defined by classes 3 to 8 of Goldschmidt's[2] classification. The incorporation of these variable Ordovician sediments has effected a considerable modification of the marginal rocks. On the western and southern margin of the intrusion this may be traced over a zone approximately 200 yards in width, and although the contamination results from the incorporation of a variable sedimentary series, there is a tendency for the development of a central hybrid type easily distinguishable in the field from the hornblende hybrids.[1] Hornfels xenoliths covering the range of the metamorphosed sediments are found throughout the marginal zone and except for a few restricted areas in which a single hornfels type appears to have been responsible for most of the changes in the contaminated rock they do not follow any systematic distribution.

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[1] Tilley, C. E., Geol. Mag., LX, 1923, 410–18.

[2] Goldschmidt, V. M., *Die Kontakt-metamorphose im Kristianiagebiet*, 1911, 483.

With the exception of quartz, biotite is the most abundant product of the metamorphism in both the greywackes and shales. Cordierite is also a constant product of both the arenaceous and argillaceous types.[2] No garnet-bearing xenoliths have been found. Hypersthene is often present but is subordinate to both biotite and cordierite. Plagioclase and diopside become important in the hornfelses of the more calcareous sediments. A little spinel is developed in the less silicic types but corundum and sillimanite have not been recorded in the xenoliths.

The variable nature of the sediments, their gradational character, and the lack of any systematic distribution makes a chemical study of the reciprocal reactions between the xenoliths and magma impossible.

THE MAIN TYPE RESULTING FROM THE CONTAMINATION.

The typical contaminated rock is well exposed in the Polsue valley. In thin section the essential constituents are plagioclase, biotite, hypersthene, quartz, and orthoclase, with a smaller amount of diopside. Apatite, sphene, and zircon are the main accessories. Two grain sizes of plagioclase are present. The plagioclase ($Ab_{45}An_{55}$, zoned to $Ab_{70}An_{30}$) of larger grain size are 0·5 to 1·0 cm. in length. A large number of dusty inclusions producing a distinct cloudiness form an intermediate zone between a clear inner core and outer rim. This clear rim is frequently pitted with rectangular inclusions of potash felspar. Hair-like needles of apatite and small hypersthene grains also occur in the clear rims and cores of the plagioclase. The plagioclase of smaller grain size is an andesine free from zoning and clouding but containing apatite as inclusions. The hypersthene is pleochroic with $X =$ pale plum, $Y =$ pale yellow, $Z =$ pale green. Biotite, ragged in form, is growing at the expense of the hypersthene. The pleochroism is strong and distinguishable from that of the biotite of the ferromagnesian clots of sedimentary origin. This is lighter in colour and has a higher apparent birefringence due to less absorption. The quartz occurs in a large number of roughly equidimensional grains varying in size from 0·05 to 0·1 cm. These are sometimes enclosed in orthoclase but more frequently they partly surround the smaller plagioclase laths. Together with the squat, stumpy plagioclase crystals they give the rock a subgranular texture. Apatite needles are very abundant and occur throughout the rock. This rock has been analysed (see table of analyses No. 5), and is comparable with the quartz-biotite-norite of Newseat, Aberdeenshire.[1] It is, however, a more acid rock with a higher content of silica, alumina, and alkalies.

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[1] Deer, W. A., op. cit., 56.

[2] Gardiner, C. I., and Reynolds, S. H., *Quart. Journ. Geol. Soc.*, lxxxviii, 1932, 26.

Earlier stages in the contamination are seen in the rock at the junction of the Old Strand with the Polsue burn. In hand specimens numerous xenoliths are seen. The rock is scattered throughout with innumerable grains of clear rounded quartz forming an interstitial mosaic between the relatively large and sometimes porphyritic plagioclases (fig. 1*b* and 1*c*). The xenoliths are distinguishable by a concentration of biotite, hypersthene, quartz, and innumerable rutile grains. Apatite needles are slightly more concentrated in the xenoliths than in the enclosing rock. (Fig. 1*a*.) A later stage is seen in the rock below the fault in the Polsue burn. It is completely uniform in appearance and shows a normal igneous texture: it may be described as a quartz-biotite-norite. Plagioclase (Ab$_{57}$An$_{43}$), characterized by close twinning planes, is the most conspicuous constituent. Biotite and hypersthene are uniformly distributed and approximately equal in amount. Quartz and orthoclase form interstitial areas of increasing importance, and the quartz frequently forms small plates that poikilitically enclose small plagioclase laths. The development of these plates may be traced from the original quartz aggregates seen in the earlier stages of the contamination to the final development in which their recrystallization is complete. They form a pool of quartz in which all indication of their origin is lost. When this advanced stage in the contamination is reached the rock differs from the typical pyroxene-biotite hybrids[2]

These are medium-grained rocks frequently heterogeneous due to injection of a quartz-potash felspar rich magma with the following range of mineralogical composition (modal).

	1	2
Quartz	13·53	14·84
Orthoclase	13·30	17·10
Plagioclase	53·60	42·05
Biotite	11·81	13·14
Hornblende	2·81	2·04
Pyroxene (mainly hypersthene)	5·63	10·36

(Analyses of 1 and 2 are given in columns 9 and 8 respectively on page 375.)

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[1] Read, H. H., *Quart. Journ. Geol. Soc.*, xci, 1935, 608.

[2] Deer, W. A., op. cit., pp. 60–1, 69–72.

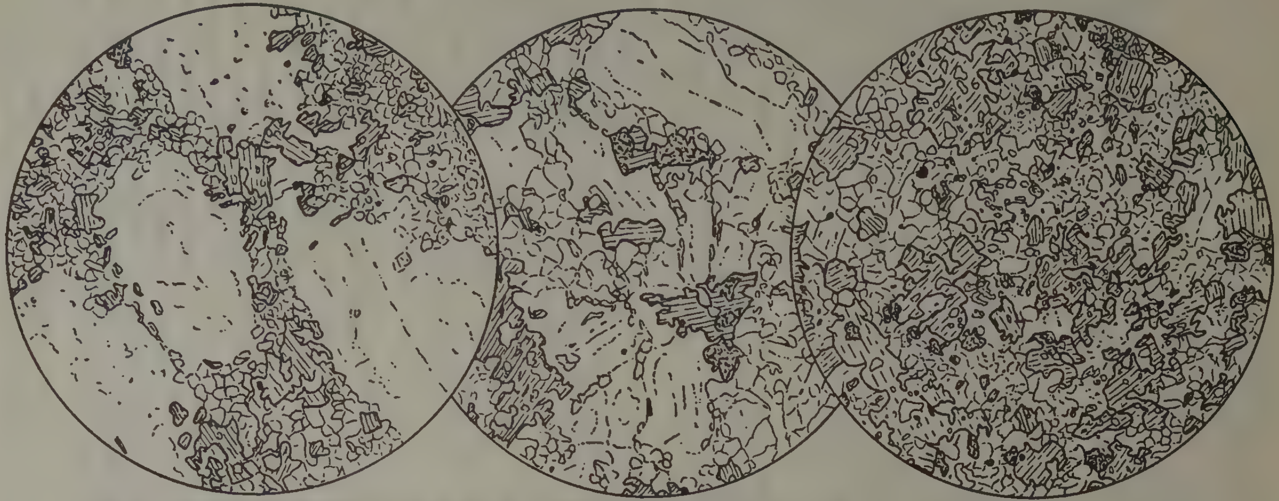

Fig. 1.—(*a*) Xenolith showing large biotite flakes with smaller irregular hypersthene; plagioclase and rounded quartz grains make up the felsic portion of the inclusion. The small black granules are rutile. (*b*) Sedimentary contaminated rock of the marginal zone showing porphyritic plagioclase sometimes with many quartz grains aligned along their margins, large plates of biotite and irregular hypersthene associated with the biotite. (*c*) Sedimentary contaminated rock of the marginal zone. Large plagioclase crystals set in medium size biotite flakes with small plagioclase and quartz grains.

only in the relative paucity of orthoclase and in the lack of the characteristic heterogeneity of those hybrids.

THE ALUMINOUS XENOLITHS AND CONTAMINATION.

Argillaceous xenoliths are best seen to the north-west of Black Shoulder. They are platy in appearance and stand out on the weathered surfaces. The assemblage is quartz, biotite, hornblende, plagioclase, spinel, with rutile, iron-ore, apatite, zircon, and a golden chlorite as accessories. The occurrence of quartz and spinel indicates a lack of equilibrium and a limited condition of diffusion existing within the xenoliths which is rapidly passed when the mechanical disintegration begins. Away from the xenolithic margin the plagioclase ($Ab_{59}An_{41}$) is slightly poikilitic and forms comparatively large plates which enclose small biotite flakes and rounded quartz grains (Fig. 2*a*). Towards the margins the xenoliths are penetrated by quartz and potash felspar wedging along intercrystal boundaries. The xenoliths are rapidly disintegrated and incorporated within the enclosing rock. The plagioclase plates of the xenoliths are also corroded by the invading potash felspar, the action of which is most effective along twin planes. In this way a single individual gives rise to a number of smaller grains with an average size of 0·25 mm. The analysis of a typical argillaceous xenolith is given in the table of analyses.

The rock contaminated by reciprocal reaction and mechanical disintegration with this argillaceous assemblage is peculiar in the rapid change of its grain size, and its relatively high percentage of biotite.[1] Areas rich in small plagioclase laths (0·25 mm.), quartz grains, and biotite are abundant and are derived by direct incorporation of the xenoliths. The remainder of the rock consists of larger plagioclase crystals ($Ab_{45}An_{55}$) 4 mm. in length, and green hornblende. The larger plagioclase individuals are invariably rimmed with a clear zone of more acid ($Ab_{60}An_{40}$) plagioclase.

THE CALCAREOUS XENOLITHS AND CONTAMINATION.

Good examples of the more calcareous xenoliths may be seen at the head of the Old Strand, a tributary of the Polsue burn. The rock is fine-grained and equigranular consisting mainly of squat tabular plagioclase ($Ab_{55}An_{45}$), and hypidiomorphic diopside, green in colour and weakly pleochroic. A little quartz is also present. Magnetite granules are common and apatite is abundant as small prisms and larger irregular grains. Towards the xenolithic margin the grain size increases and mechanical disintegration of the hornfels begins. This is accompanied by the inversion of the diopside to a green hornblende (compare Nockolds,[2] 1934) and finally to biotite.

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[1] Nockolds, S. R., *Quart. Journ. Geol. Soc.*, xc, 1934, 308.

[2] Nockolds, S. R., op. cit., p. 313.

The increase in grain size of the ferromagnesian constituents is also shown by the plagioclase, but the small quartz grains remain unaltered. The biotite grows round and includes the quartz but the growing plagioclase laths rarely enclose the quartzes which are frequently aligned along the periphery of the felspars. Analysis of a calcareous xenolith is given in the table (No. 2). Xenoliths derived from less calcareous hornfelses than that analysed reached phasal equilibrium more quickly and reciprocal reaction is soon superseded by mechanical disintegration.

It is not possible to make a quantitative study of the process of reciprocal reaction because, although the zone of increased grain size without any mechanical addition could be separated for analysis, the exact composition of the magma enclosing the xenoliths is not known. An analysis of the contaminated rock was made (analysis 6) to compare with the general type resulting from the composite contamination of the varying hornfelses. The analysis shows a marked convergence towards the main type but contains more lime and less magnesia.

THE ARENACEOUS XENOLITHS AND CONTAMINATION.

The arenaceous hornfels xenoliths derived from the greywackes are essentially quartz-biotite assemblages (Fig. 3*a* and analysis 3). The quartz is irregular in its grain size which varies considerably within a single slide, while the biotite flakes are small and uniformly distributed. Cordierite is usually present in appreciable amount, but has frequently been replaced by a micaceous alteration product. Of less importance are a few orthoclase plates poikilitically enclosing small quartz grains. A little muscovite is sometimes present, and apatite, zircon, and magnetite complete the accessories. Included within this group are the conglomerate xenoliths. The assemblage is the same as the finer grained hornfelses of the greywackes but areas rich in hypersthene occur (Fig. 3*b*).

The difficulty of completely separating the effects of the various sedimentary types contributing to the contamination is apparent when two different xenolithic assemblages occur within the limited area of a single slide. This is illustrated by a specimen taken close to the contact with the country rock on the south side of Dodd Hill. In hand specimens a number of different xenoliths can be seen enclosed within the contaminated rock which looks more metamorphic than igneous. Representing a high degree of contamination, it can only be described as a mixed rock (analysis 4. This shows a close comparison with the analysis of the "fused sediment" from Slievenisky, Newry Igneous Complex),[1] and has a rough modal composition; plagioclase, 30 per cent; quartz, 30 per cent; biotite, 20 per cent; muscovite, 15 per cent; and accessories (apatite and

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[1] Reynolds, D. L., *Quart. Journ. Geol. Soc.*, xc, 1934, 603.

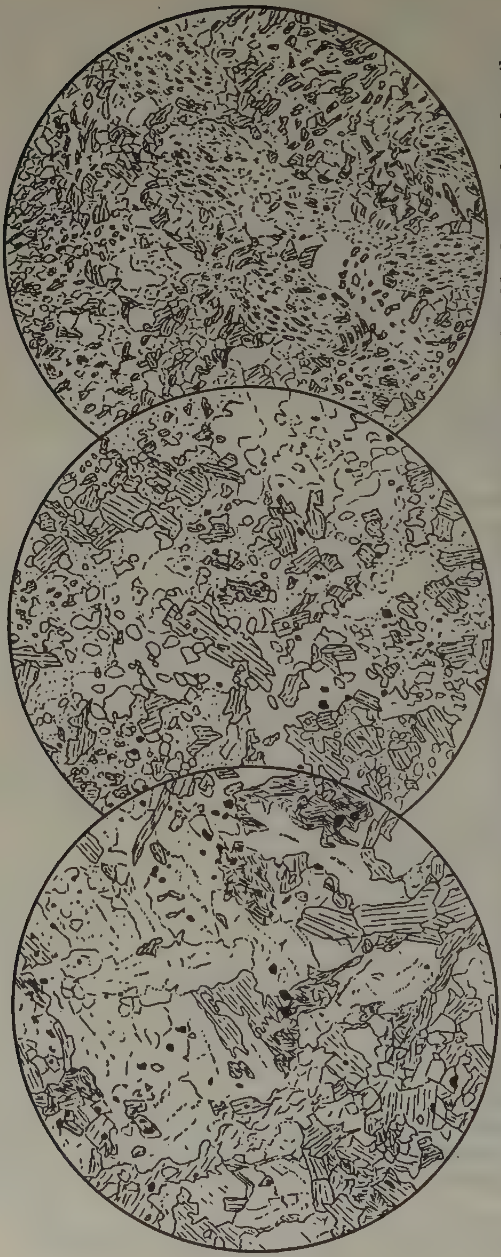

FIG. 2.—(*a*) Aluminous xenolith. Main constituents are plagioclase and biotite. Quartz, hornblende, spinel, and rutile also occur, the two later minerals are indicated as black grains. (*b*) Xenolith showing large cordierite crystals (dotted) with many inclusions of biotite and plagioclase. Small quartz grains are also present. (*c*) Xenolith of large sieve cordierites with inclusions of biotite. A little quartz and plagioclase occurs in between the large cordierites.

sphene), 5 per cent (Fig. 3*c*). Enclosed are the xenoliths from which the quartz and mica are derived. Some are essentially quartz-biotite-hornfelses and others quartz-biotite-cordierite assemblages (Fig. 2*c*). The muscovite is derived from the latter by alteration of the cordierite.

A comparable result is obtained by the contamination of acid veins of microperthite, plagioclase, and quartz penetrating the hornfels of the country rock at Beninner (Fig. 2*b*). Here cordierite is the most important product of the metamorphism. Within the hornfels it occurs in well-developed individuals, the basal sections of which often show symmetrical extinction in twins at 30° from the twinning line. In proximity to the acid veining it alters first to an isotropic product and finally to muscovite and chlorite. A fibrous intermediate product with low birefringence sometimes takes the place of the isotropic material. Biotite is also present in the hornfels and this together with the muscovite is mechanically incorporated within the acid veins.

On the eastern side of the intrusion the marginal rocks appear to be less affected by the incorporation of the sediments. On the whole they are fine-grained rocks of medium to dark colour. Light and dark patches often present a heterogeneous appearance and are indicative of the hybrid character of these rocks. An analysis, as representative as possible, of the rocks of the eastern margin is given in the table (analysis 7). The plagioclase, an andesine, occurs in lath-shaped individuals and is frequently crowded with small inclusions. Phenocrysts are uncommon and the grains are equidimensional. The proportions of monoclinic and rhombic pyroxene, biotite, and green hornblende vary. The hornblende is usually formed rimming the augite. Biotite occurs as independent flakes as well as round both the pyroxenes. Small interstitial pools of quartz and potash felspar occur and sometimes become important constituents. Apatite is an abundant accessory.

THE FORMATION OF THE MARGINAL ROCKS.

Before a discussion of the development of the rocks of this outer margin is possible, the composition of the magma in which the incorporation of the sedimentary xenoliths took place must be considered.

It has been shown already that the rocks lying inside the zone of sedimentary contamination are hybrids of gabbro-tonalite origin. The second intrusion of tonalite overwhelmed the first in the northern side of the complex and here the tonalite is in contact with the sediments. The uncontaminated character of the tonalite and the dominance of a moderately basic felspar of the marginal contaminated rocks is sufficient negative evidence to exclude the possibility that the intrusion of the tonalite was the sole factor in the production of this marginal zone. The tonalite contact with the arenaceous and shaly sediments at Craighorn sufficiently emphasizes the difference

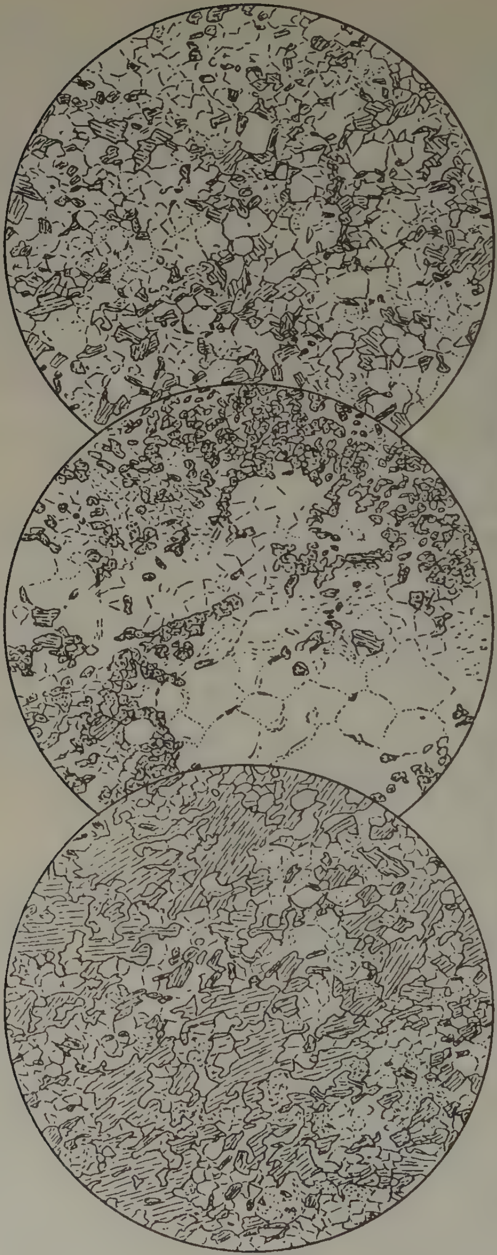

FIG. 3.—(*a*) Arenaceous xenolith. Assemblage, biotite, quartz, and plagioclase (dotted). (*b*) Hornfelsed xenolith of pebbly grit showing large areas of recrystallized quartz, and areas rich in granular hypersthene with a little biotite. (*c*) Sedimentary contaminated rock of the marginal zone showing the "mixed" character of the highly contaminated type. Biotite, muscovite, quartz, and plagioclase (dotted).

of the hornblende-hybrids and tonalite contact with the surrounding sediments. Here the incorporation of the sediments is strictly limited to a very narrow zone in which the orthoclase of the tonalite at the immediate contact encloses numerous quartz grains, and in which biotite of sedimentary origin is abundant.

There is no evidence that the outer basic zone was a hybrid, resulting from the deep seated assimilation of gabbro by tonalite. It has been shown that the gabbro was emplaced and crystallized before the tonalite was intruded. The zone of sedimentary contamination is therefore not simply the incorporation of greywackes and shales within a gabbro-tonalite hybrid.

The alternative proposition is that the sedimentary contamination took place before the intrusion of the tonalite, and *ipso facto*, that the magma incorporating the sediments was originally a gabbro. Reviewing the facts we see that the rocks of the outermost zone are on the whole more acid than the hornblende hybrids but closely allied to the pyroxene-biotite hybrids in chemical composition. The altered gabbro lenses and the hornblende hybrids are unaffected by the incorporation of the sediments, because of their distance from the contact. The bulk of the incorporated material being derived from psammitic and even psephitic sediments, with a smaller amount of pelitic, has resulted in the contaminated product being dominantly arenaceous, slightly modified by the aluminous shales. Xenoliths covering this compositional range are easily converted into an assemblage capable of quick incorporation in a gabbro magma, as the bulk of them will be directly assimilated by mechanical disintegration. These xenoliths belonging to a later stage in the reaction series produce a granitization of the gabbro magma. The incorporation of silica and alumina-rich xenoliths is well known to favour the development of orthopyroxene and to increase the anorthite content of the plagioclase.[1]

This result is characteristic in the author's opinion, not only of the marginal rocks of the Cairnsmore complex, but of the other smaller intrusions of the Southern Uplands.[2] The resulting contaminated rock is a quartz-norite in mineral and chemical composition. This rock now closely resembles the pyroxene-biotite hybrids, but differing slightly in texture and being poorer in alkalies (see analyses 5, 6, 8, and 9, especially the normative felspar). This difference is due to a more intensive acidification at the time of the tonalite intrusion. These pyroxene-biotite hybrids are frequently characteristically heterogeneous and are the result of the incomplete mixing of the permeating "partial magma" of quartz and potash-felspar and the injected quartz-norite. The production of the pyroxene-biotite hybrids may be expressed diagrammatically.

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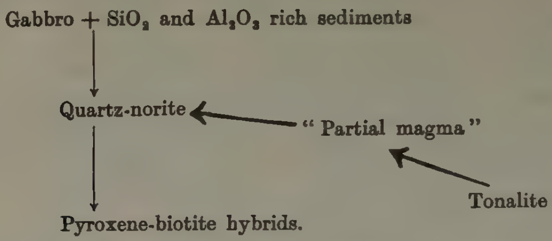
[1] Bowen, N. L., *The Evolution of the Igneous Rocks*, Princeton, 1928, 208, and others.

[2] Walker, F., *Trans. Edinb. Geol. Soc.*, xl, 1925, 357, and GEOL. MAG., LXV, 1928, 153.


Gabbro + SiO_2 and Al_2O_3 rich sediments
Quartz-norite
"Partial magma"
Tonalite
Pyroxene-biotite hybrids.

If the intrusion is regarded as a laccolith[1] no difficulty is presented by the present spatial arrangement of the marginal rocks and the pyroxene-biotite hybrids. Although these hybrids are now separated from the zone of sedimentary contamination by the erosion of the Laggeran and Polsue burns there is little doubt of their former continuity with it, and of their origin by subsequent hybridization by the quartz, potash-felspar "partial magma". A section across the western portion of the mass showing the relationship of the pyroxene-biotite hybrids to the marginal rocks is shown in Fig. 4.

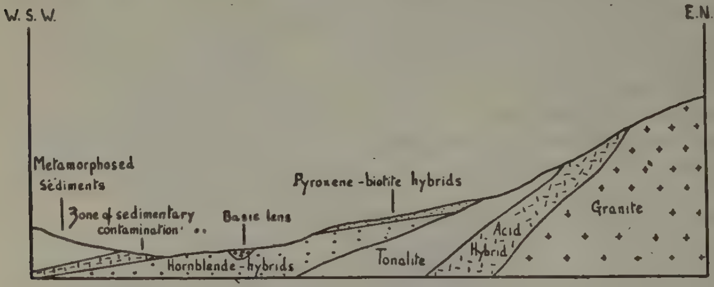


FIG. 4.—Section across the western half of the Cairnsmore intrusion showing the suggested laccolithic arrangement and the relationship between the pyroxene-biotite-hybrids and the marginal zone of sedimentary contamination.

THE ANALYSES AND VARIATION-DIAGRAM.

The analyses of the hornfels xenoliths and the contaminated rocks together with those of the pyroxene-biotite hybrids have been plotted on a normative diagram (Fig. 5). The three analyses of the sedimentary contaminated rocks fall approximately on the same isonormative line for (Or + Cor) but vary in the Ab-content. The rock from the eastern side (No. 7) does not show the general effect of the contamination and is not so typical. This is due to less extensive secondary effects due to the tonalite. In order to obtain an estimate of the relative amount of greywacke and shale added to the gabbro a linear variation diagram was plotted. The silica percentage of the material added is 62 per cent, and a further calculation shows that approximately 66 per cent of the whole is derived from the greywackes and 34 per cent from the shales.

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[1] Deer, W. A., op. cit., p. 64.

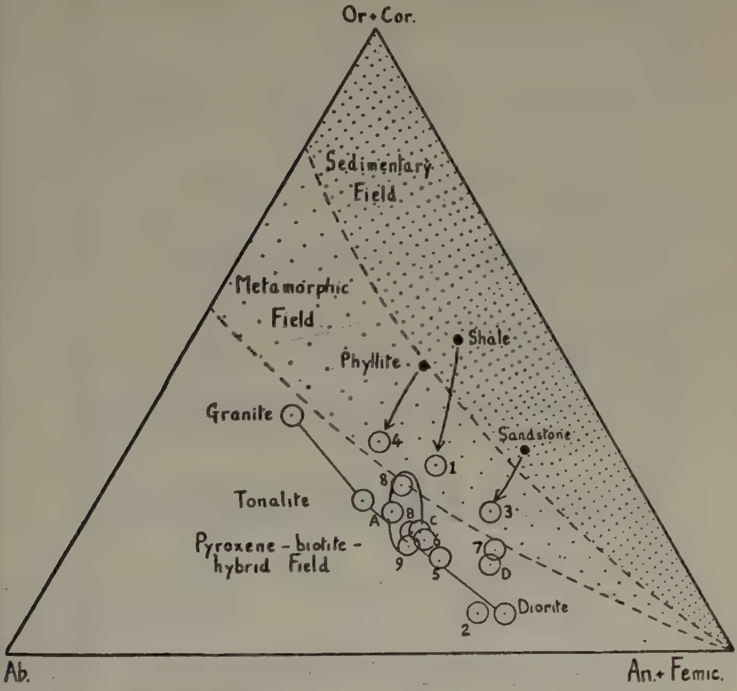

FIG. 5.—Normative diagram (excluding quartz). The sedimentary and metamorphic fields and the points for phyllite, shale, and sandstone are taken from Brammall's diagram (GEOL. MAG., 1933). The points for granite, tonalite, and diorite and the pyroxene-biotite-hybrid field are taken from fig. 5, *Quart. Journ. Geol. Soc.*, 1935, 69. The numbers 1–9 and A to D refer to the table of analyses, p. 374.

A similar deduction cannot be made for the more typical type because of the almost certain acid addition at the time of the tonalite intrusion and the subsequent hybridization of the original gabbro. The analyses of the more typical type so well developed along the western contact are more instructive. A small initial gain in soda, as noticed by Brammall[1] in the rocks of the Dartmoor

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[1] Brammall, A., and H. F. Harwood, *Quart. Journ. Geol. Soc.*, lxxxviii, 1932, 171.

TABLE OF ANALYSES.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	A.	B.	C.	D.
SiO_2	45·35	53·82	68·56	62·10	60·02	62·57	57·84	60·88	62·07	59·55	57·15	57·46	56·19
Al_2O_3	25·49	19·39	13·20	17·32	17·61	15·96	17·57	15·91	16·05	17·80	18·39	19·64	15·86
Fe_2O_3	3·34	1·63	0·95	1·48	0·48	1·44	2·06	1·30	1·35	1·12	1·42	0·46	0·64
FeO	6·70	5·42	6·53	5·38	5·14	4·73	5·35	4·84	5·08	4·14	4·25	4·96	9·03
MgO	5·17	2·80	2·91	2·70	4·05	2·44	3·72	3·07	2·82	2·86	3·54	2·41	3·52
CaO	3·85	9·71	2·82	1·09	5·23	5·57	5·83	4·25	4·57	4·10	5·75	5·70	6·20
Na_2O	3·56	3·86	1·64	2·75	3·27	3·72	2·47	4·07	3·64	3·71	3·81	3·60	2·62
K_2O	3·40	1·10	1·32	2·71	2·36	2·54	2·24	3·40	2·41	3·22	2·99	2·65	2·06
(+ 105° C) H_2O	1·66	0·62	0·92	1·98	0·20	0·14	1·12	0·28	0·40	1·90	0·20	1·10	0·71
(– 105° C) H_2O	0·40	0·17	0·19	0·14	0·18	0·22	0·32	0·21	0·15	0·45	0·80	0·55	0·13
TiO_2	1·30	0·91	0·89	0·90	1·31	0·78	1·18	1·50	1·29	1·00	0·75	1·10	2·89
P_2O_5	0·24	0·93	0·42	0·21	0·31	0·15	0·16	0·26	0·30	0·19	0·22	0·26	0·10
MnO	0·03	0·07	0·05	0·06	0·02	0·03	0·04	0·02	trace	trace	0·15	trace	0·12
SO_3	—	—	—	1·50	—	—	—	—	—	*nil*	trace	*nil*	—
CO_2	—	—	—	—	—	—	—	—	—	*nil*	0·55	*nil*	—
	100·49	100·43	100·40	100·32	100·18	100·29	99·90	99·99	100·13	100·04	99·97	99·89	100·07

NORMS.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	A.	B.	C.	D.
Quartz	—	2·42	40·38	26·70	12·54	14·82	14·64	10·74	15·60	10·80	5·58	8·40	10·86
Orthoclase	20·02	6·67	7·78	16·12	13·35	15·01	12·79	23·91	13·90	18·90	17·54	15·57	11·68
Albite	26·72	32·49	13·62	23·58	27·77	31·44	20·96	28·82	31·44	31·44	31·96	30·39	22·01
Nepheline	1·70	—	—	—	—	—	—	—	—	—	—	—	—
Anorthite	17·79	32·25	11·40	4·73	24·46	19·46	28·08	15·85	20·02	19·46	24·46	26·41	25·85
Corundum	9·48	—	4·90	8·16	0·82	—	0·92	—	—	1·12	—	1·12	—
Diopside	—	8·84	—	—	—	5·97	—	3·29	0·68	—	—	—	4·18
Hypersthene	—	9·94	17·10	12·64	16·96	9·35	15·50	11·42	12·87	12·08	14·58	12·73	17·93
Olivine	14·81	—	—	—	—	—	—	—	—	—	—	—	—
Magnetite	4·87	2·32	1·39	2·09	0·70	2·09	3·02	1·86	1·86	1·62	2·09	0·70	0·93
Ilmenite	2·43	1·67	1·67	1·67	2·42	1·57	2·28	2·89	2·43	1·98	1·37	2·13	5·47
Apatite	0·51	2·02	1·01	0·44	0·67	0·34	0·34	0·62	0·67	0·34	0·34	0·67	—
Pyrites	—	—	—	1·67	—	—	—	—	—	—	—	—	—
Calcite	—	—	—	—	—	—	—	—	—	—	1·20	—	—
Water	2·06	1·72	1·11	2·12	0·38	0·36	1·44	0·49	0·55	2·35	1·00	1·65	0·84
	100·39	100·34	100·36	99·92	100·07	100·41	99·97	99·89	100·02	100·09	100·12	99·77	99·75

intrusion, demonstrates their relationship with the hornblende-hybrids. The two analyses lie close to the beginning of the pyroxene-biotite field and indicate the close relationship between the sedimentary contaminated rocks and these hybrids. The subsequent dependence of the formation of the pyroxene-biotite hybrids on the " partial magma " rich in quartz and potash felspar is seen in the line showing the change of differentiation which now becomes more isonormative with regard to the Ab-content and shows a steady increase towards (Or + Cor). It is, however, obvious from the diagram that the greywackes and shales have exercised a predominating influence on the character of the contamination and that the effects of the more calcareous hornfelses are of little importance. It would also appear that rocks five and six cannot be derived exclusively from an admixture of the metamorphosed sediments and the original gabbro but have been affected by the later igneous hybridization which finally culminated in the formation of the pyroxene-biotite hybrids. It is this overlapping of the effects of sedimentary contamination and igneous hybridization which makes the quantitative study of both the chemical and mineralogical changes impossible.

1.—Xenolith : assemblage, rutile, plagioclase, quartz, hornblende, biotite, spinel with rutile and magnetite. North-West Black Shoulder. (Analyst : W. A. Deer.)

2.—Xenolith : assemblage, plagioclase, diopside. Old Strand, Polsue burn. (Analyst : W. A. Deer.)

3.—Xenolith : assemblage, quartz, biotite, hypersthene, cordierite, plagioclase. Head of Laggeran burn. (Analyst : W. A. Deer.)

4.—Hybrid : Head of Laggeran burn. (Analyst : W. A. Deer.)

5.—Hybrid : South-East slope of Dodd Hill. (Analyst : W. A. Deer.)

6.—Hybrid : Old Strand, Polsue burn. (Analyst : W. A. Deer.)

7.—Hybrid : Between Moorbrock and Green Hill, East of Cairnsmore. (Analyst : W. A. Deer.)

8.—Pyroxene-biotite hybrid. Watershed between Laggeran and Polsue burns. East Cairnsmore. (Analyst : W. A. Deer.)

9.—Pyroxene-biotite hybrid. Head of Polsue burn. East Cairnsmore. (Analyst : W. A. Deer.) (Analyses 8 and 9 are quoted from the *Quarterly Journal of the Geological Society*, xci ; Table opposite p. 72.)

A.—Hornblende-biotite-granodiorite, with accessory pyroxene. Sheet Hill, southern margin of mass, Spango Water. (Analyst : W. H. Herdsman.) (Walker, 1925, p. 161.)

B.—Augite-biotite-quartz-diorite. Margin of Priestlaw in Faseny Water. (Analyst : W. H. Herdsman.) (Walker, 1925, p. 161.)

C.—Quartz-biotite-hyperite-porphyrite. River Whiteadder, eastern margin of Cockburnlaw mass. (Analyst : W. H. Herdsman.) (Walker, 1925, p. 161.)

D.—Quartz-biotite-norite. Quarry half a mile south of Newseat, Methlick, Aberdeenshire. (Analyst : S. Parker.) (Read, 1935, p. 608.)

The Origin of Lulworth Cove, Dorsetshire.

By E. St. John Burton

THE well known Lulworth Cove, situated on the Dorsetshire coast between Mupe Bay, on the east, and Dungy Head, on the west, is generally considered to be a very good example of the result of marine erosion acting upon rocks of unequal resistance, and such indeed it is.

The formation of the Cove was rendered possible by a breach, about 400 feet in width, made by long-continued wave action against the inclined wall of Portland Stone fronting the sea. Lulworth Cove, in fact, offers a remarkable and to some extent peculiar instance of coast erosion. Geological literature dealing with this part of the coast emphasizes the point that Lulworth Cove owes its origin to the breach made at some time through the barrier of Portland Stone, and that subsequently to this event the overlying and less resistant Purbeck and Wealden Beds were worn away until the sea had advanced sufficiently far to reach the more serious obstacle offered by the upturned Chalk lying across the northern end of the Cove.

So much is clear from a brief survey of the Cove itself. This has the appearance of being nearly circular in form, but it is obtusely oval, because the two flanks being chiefly in Wealden Beds have retreated more rapidly than the southern and northern parts. Now, an inspection of the 1 in. Geological Survey Maps (Sheets 342, 343), shows that along the coast-line there is a certain number of coves and bays, both large and small. Some of them are quite small coves, such as Bacon Hole and Pondfield. Others are fairly wide bays; but whatever their point of origin, none quite resembles Lulworth Cove, although Pondfield might have assumed a similar form, had it not been for the loss of land westward of Worbarrow Tout. At Worbarrow Bay, physiographical changes seem to have operated in a different manner to those at Lulworth. But before we accept any of these examples as being simply cases of marine aggression, it may be expedient to consider whether earlier conditions of physical geography may not have played a very important part in determining the results produced.

It is the purpose of the present paper to attempt some explanation regarding the changes which have led to the formation of Lulworth Cove. The inquiry may reasonably embrace the question as to why Lulworth Cove has no counterpart elsewhere on the coast. The Cove, naturally, marks a stage in coast erosion, with the reservation, however, that such coves are not formed where the Portland and Purbeck Beds are only inclined at a low angle, or where they dip seaward. That is apparent from observation along the coast section from Swanage to Chapman's Pool. But the evidence is not conclusive that Lulworth Cove was primarily due to the action of the sea, however irregular the progress of coast erosion may have been elsewhere, and in the author's opinion it fails to account not only for the form and extent of Lulworth Cove, but also for its geographical position on the coast.

Stair Hole, Lulworth Cove, and Worbarrow Bay, have been cited (1) (2) as illustrating progressive stages in coast erosion. Strahan (1) certainly mentions the dependence of coast erosion on geological structure, but he may be understood to refer here only to the alternation of hard and soft beds in a more or less inclined position.

The first of these examples (Stair Hole), shows the breaching of the Portland Stone in three places, and the consequent wasting away of the Purbeck and Wealden Beds. The second (Lulworth Cove), demonstrates a more advanced stage, where the sea has made a breach wide enough to enable a direct attack to be instituted, and a more comprehensive removal of the softer beds within to take place. The third example (Worbarrow Bay), is given to mark a still more advanced condition, resulting in the formation of a wide bay by the almost entire removal of the Portland Stone and Purbeck Beds and all the Wealden Beds, originally extending in unbroken succession across Worbarrow Bay, to the coast opposite at Mupe Rocks, a distance of over one mile and a half. This last case can hardly be disputed, unless the view is adopted that displacements of Jurassic and Cretaceous rocks along this particular line of coast had already occurred before the Tertiary uplift, and that therefore they represent the results of two separate series of earth movements, which are known to have taken place in Dorset at two different (inter-Cretaceous and Tertiary) geological periods. The possibility of the strata having been involved in more than one disturbance should not be neglected, regular though the succession appears to be.

It is of course true that the Jurassics have yielded unevenly to pressure at different points, and may have sagged; but apart from this, if we treat these disproportionate effects of coast erosion as being penecontemporaneous with one another, and there is no direct reason for supposing otherwise, the anomaly must be envisaged that the results attained by the sea acting upon one part of the barrier of Portland Stone, compared with the results upon another, have been immeasurably greater.

It is difficult to imagine how structural weaknesses of the relatively homogeneous Portland Stone could be alone responsible for such far reaching effects of marine aggression as those seen at Worbarrow Bay.

One of the results of the Tertiary movements, as far as regards the immediate neighbourhood of Lulworth Cove, was embodied in an increased compression of the Upper Jurassic and Cretaceous rocks uplifted by the faulted anticlinal (Purbeck Anticline) so well seen eastward at Ballard Point, near Swanage (3). Lulworth Cove owes its origin primarily to conditions of physical geography and drainage, and secondarily, a very different matter, to marine erosion becoming efficacious only by the structure, height above sea-level, and disturbed state of the Jurassic rocks immediately fronting the sea.

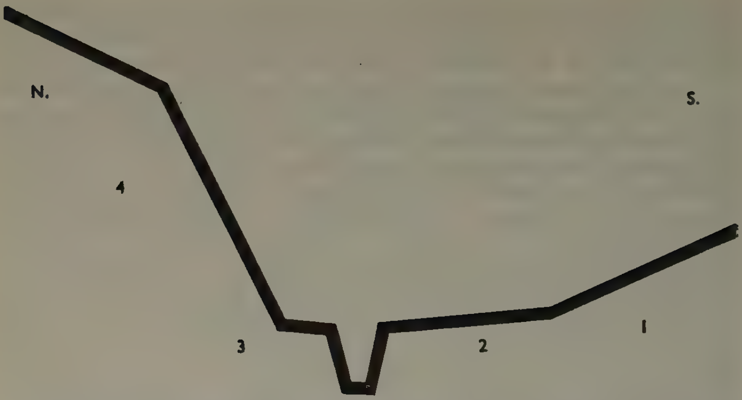
The chief points in support of this view may be rendered intelligible by a consideration of the local geographical conditions existing at the time when the valleys were in course of formation, and when the land surface was relatively higher in relation to the site of Lulworth Cove than it is now. If the road descending to West Lulworth is followed until a point is reached opposite the Dorchester and Weymouth Road, south of the church, there will be observed a meadow-flat, about 65 feet, O.D., and about 100 yards in width. This receives the drainage southward, the remnant of an earlier and more important southerly drainage from what may be here termed the northern upland, attaining at its most elevated part a height of 544 feet, O.D., one mile north from Lulworth Cove, and merging on the west side into the Chalk plateau of Chaldon Down (500 feet, O.D.). The upland extends across the head of the main valley at Lulworth. The meadow-flat receives drainage from three shallow valleys transverse to the main valley, all of which enter it from the western side. A low hill separates the first two valleys, whose floors slope gently down to the mead. The third and last valley, situated between Hambury Tout (454 feet, O.D.), and the coast, shows a fairly flat floor about 100 yards wide. The gradient of this is sufficiently well marked, being approximately 1 foot in 10 yards, increasing in steepness just before joining the principal valley, where the mead intersects it. The floor of this short valley has been excavated chiefly in Wealden Beds; its northern flank in the highly inclined Chalk; and the southern flank, in passage beds between Purbeck Beds and the Wealden.

The main valley at a point opposite Hambury Tout, turns eastward, the floor having a somewhat increased gradient. Following this, we find the southern edge of the floor to be about 90 yards wide. It is downcut on the left side, 50 yards south of the copious spring at 40 feet, O.D.

The re-excavation of the floor was subsequent to an advance of the sea, following changes of the coast-line in Pleistocene times. The ravine formed by the adjustment of the stream-bed to a lower level that that of the older floor is well seen in descending the narrow roadway just above Lulworth Cove. The right bank best defines the edge of the earlier floor, taking into allowance the effects of solifluxion and solution, and it is at this point about 50 feet, O.D. The left bank is ill defined and much narrower, owing to the abrupt slope forming the western termination of Bindon Hill (551 feet, O.D.).

The valley is thus excavated in the following manner, expressed diagrammatically :—

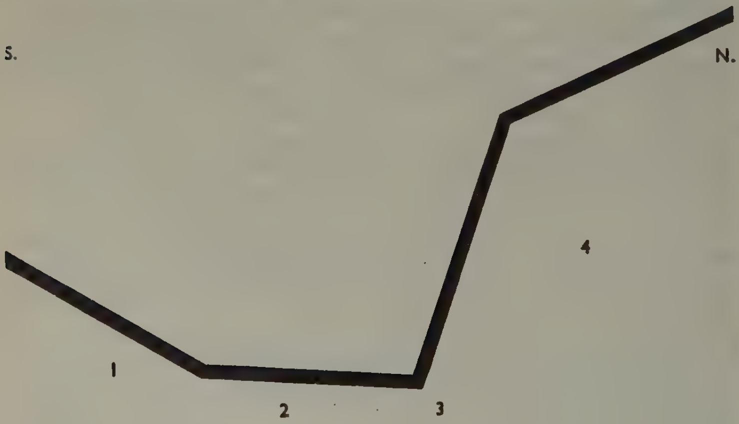
The southern drainage, having crossed the upturned edges of the inclined Cretaceous rocks, finally turned seawards and *against* the steep northerly dip of the Wealden and Jurassic Beds.



Text-fig. 1.—Diagram illustrating the form of the valley at Lulworth Cove. The middle portion of the outline shows the re-excavation of the floor. The numerals refer to the following beds:—(1) Purbeck Beds. (2) Wealden. (3) Upper Greensand and Gault. (4) Chalk. All the beds are inclined at a high angle.

Higher up the valley, at Hambury Tout, we see the same form, without, of course, any re-excavation of the floor as at Lulworth Cove.

The drainage, as in other cases besides that of Lulworth, has ignored the tectonics of the strata over which it passed. The shallow valley in the Wealden on the east side of Lulworth Cove, which has apparently no relation with that at Hambury Tout, on the western side, is also downcut to its lowest level, but originally extended to a point about the centre of the Cove.



Text-fig. 2.—Diagram illustrating the form of valley at Hambury Tout. (1) Purbeck Beds. (2) Wealden. (3) Upper Greensand and Gault. (4) Chalk. The beds are vertical or inverted, except on the extreme left of diagram.

The stream entering this from the opposite side, must at one time have run at a higher level, in order to effect an outlet where now is the entrance to Lulworth Cove, and having reached that point, it eventually cut a narrow V-shaped ravine, which retreated, as in the case of other examples seen at Chapman's Pool, Winspit, and Tilly Whim, farther east on the Dorsetshire coast, until the stream-bed was finally adjusted to the lower level required by the process of re-excavation, and further downcutting became unnecessary (see Bury, 4).

The features of re-excavation of the earlier and higher floors of all the short valleys at the localities above cited, are exactly similar to those at Lulworth Cove, but on a larger scale. Every ravine of this special character, on the coast, exemplifies re-excavation of older floors, during the recession of the former coast-line; a recession due to the advance of the sea upon previously existing land lying to the south (5). Subsequently to the invasion by the sea of a great southern valley through which flowed a river comparable to the Rhine, these nearly flat-bottomed valleys were converted at their southern ends into hanging valleys, for the reason that the actual openings at this stage of the advance were as much as 60 feet above sea level.

It would not be a very difficult task for the then existing stream at Lulworth to erode its banks and adjust its gradient to the lower level required by erosion of the Purbeck Beds at the entrance to Lulworth Cove, and although it was obliged to cut a channel through them, and against the dip, it might be borne in mind that confluent drainage over the site of what is now Lulworth Cove was directed south, having received the lesser drainage from the areas immediately west and east of this. An effluent must have been found somewhere, and in the author's opinion, the position is shown by the present entrance to Lulworth Cove, and while the Portland Stone is not liable to exhibit structural curves within such short distances, the elevation of the formerly existing barrier across the entrance would not have been great. Moreover, West Point and East Point mark the remains of this barrier.

It may be said that the portrayal of apparent undulations, in drawn Geological Sections of the coast-line, may lead to misunderstanding because they cannot be distinguished thus from real anticlinal and synclinal structures except by one who is wholly familiar with the tectonics. Miniature anticlinals and synclinals which do not constitute apparent undulations, and therefore are not dependent on variations in the direction or steepness of the cliff, may be seen just eastward of Durlston near Swanage, in the direction of Peveril Point. The sea accomplished the work of breaking down the basal Portland Stone at Lulworth Cove and widening the entrance sufficiently to allow the removal of the inner and less resistant rocks composing the Purbeck and Wealden Beds, next in order of superposition. But the efficacy of the lateral drainage, even at this stage, was enough to increase solifluxion and finally extensive foundering on the part of the Wealden Beds, when once the curve of the Cove had commenced development and had continued until it attained its present and very attractive form.

There yet remains to consider Stair Hole, situated between West Point and Dungy Head. Stair Hole is less than one-third the width of Lulworth Cove, and the sea has made an entrance in three places. That on the west side is a complete breach from top to bottom of the rampart of Portland Stone which at this locality is more highly inclined than at the Cove. The overlying Purbecks are faulted and contorted, and the series exhibits a very disturbed condition.

It can easily be imagined that the sea had not to break through the major thickness of Portland Beds, but before any substantial advance could be made by wave action, after having penetrated the Portland Stone, the Purbeck and Wealden Beds had to be in part removed.

This at first sight appears to be a clear case of marine erosion, without postulating physical changes in geography. Yet, on further examining the immediate area, it is noticed that several springs issue from the junction of the Purbeck Beds and the Wealden. One of these springs, especially active during wet seasons, has provenance from the direction of Dungy Head, and is causing considerable wastage, besides being responsible for cliff-falls. Although the ground immediately north of the coastal escarpments forms a long slope down to the main valley, the chief line of drainage follows the strike of the rocks, and independently at least of the northerly slope to Lulworth Cove. Subterranean water seems thus to be held up by the Wealden clays, and emergence is effected between them and limestone of Purbeck age. In other words, it makes progress between the upturned edges of the strata.

Such a constitution of local drainage has been in operation for a long time, that is before the development of Stair Hole or of Lulworth Cove. Most of the drainage, a mere remnant of an earlier southern system, eventually crosses the strike whenever the opportunity is best provided by relatively lower ground, and the exposures of steeply inclined surfaces of the Jurassic rocks above Little Beach, in the vicinity of West Point, show marked results of subaerial denudation, which at Stair Hole, by saturation and solution, has largely determined the initiation and enlargment of this impressive feature.

We have already seen, both at Lulworth and at other localities along the Dorsetshire coast, how early physiographical and drainage conditions have played the more important part in producing those special results of erosion that constitute such striking features in the geographical disposition of the present coast-line.

If at any time there had been no more than a slight drainage down the Lulworth valley, it might well have proved a difficult matter, not only for the formation of Stair Hole, but also for that of Lulworth Cove.

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REVIEW.

THE SHONKIN SAG LACCOLITH. By J. D. BARKSDALE. *Amer. Jour. Sci.*, xxxiii, 1937, 321–359.

FOR many years past the Shonkin Sag laccolith has been regarded as a classical example of differentiation in place in a single intrusion. An examination based on much detailed field and laboratory work has revealed many difficulties in this explanation, and the author accounts for the marked horizontal layering of the different rock-types by three separate intrusions. These have probably been derived by deep-seated differentiation from one primary magma, though there is nothing to show by what process this primary separation was effected. It is suggested that the second intrusion was injected along the still liquid centre of the preceding one, and the third along the base of the second. The channel of intrusion has not been found.

CORRESPONDENCE.

THE PALISADE SILL OF NEW JERSEY.

SIR,—The Palisade diabase sill of New Jersey has been widely cited as one of the most convincing examples of gravitational differentiation ever since the very complete description of J. V. Lewis in 1907. In the course of a re-investigation of the intrusion, however, I have found that its mode of differentiation is probably more complex than previous accounts would lead one to believe. The following questions, for instance, arise:—

(1) There is a marked discrepancy in composition between the chilled contact-modifications of the sill (which are holocrystalline, and contain about 2 per cent of olivine but no quartz) and the sill

as a whole. If all the olivine of the sill be considered to have combined with some of the free quartz, there will still be at least 7 per cent of quartz left if averaged over the whole sill. Is this not a strong case for syntexis with the adjacent arkose ? In this connection an irregular 3 in. vein was found (near the base of the Englewood Cliff section) which appeared to consist of altered quartzose sediment.

(ii) The olivine ledge occurs about 60 feet from the base of the sill on top of normal diabase quite as coarse as that immediately above the ledge. Is not this position very high for a stratum supposed to rest on the chilled contact phase, even in spite of the great thickness (800 feet) of the intrusion ?

(iii) The percentage of olivine in the olivine ledge is at a maximum of 17 (by volume) at the centre, and falls off to 11 per cent at the top and bottom. How may this be reconciled with the settling of early formed olivine crystals through a fluid magma on to the solid contact phase ? Should not the percentage of olivine show a definite downward increase under such conditions ? There is, moreover, a complete absence of the packing of the olivine crystals which might be expected if the settling took place in a fluid magma. If, on the other hand, increasing viscosity ended the settling, why does not the olivine ledge show a gradational instead of a sharp upper contact ?

(iv) The hard " dikes " and bands in the olivine ledge, which appear to be intrusive into it, have the same composition as the olivine-rich diabase, with the addition of a considerable proportion of late biotite. May they not, therefore, represent the paths of juvenile and hydrothermal solutions which caused the development of the mica and a hardening effect upon the olivine-diabase ?

Another point of interest is the detection of abundant hypersthene and pigeonite besides the normal augite. I hope before the close of the year to complete a survey of the sill, which will find an answer to these questions. While this letter was being drafted, I learned that Dr. E. B. Bailey had a paper on the olivine ledge about to go to Press. Dr. Bailey very kindly allowed me to read the typescript, but, as his conclusions differ from mine in some particulars, discussion may conveniently be postponed until his paper is in print.

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28th June, 1937.

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ORIGINAL ARTICLES.

Scottish Carboniferous Crinoids.

By James Wright.

(PLATES XIII-XVI.)

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  4. " *spiniger* sp. nov.
  5. *Camptocrinus compressus* sp. nov.
  6. *Poteriocrinus scotocarbonarius* sp. nov.
  7. " *pentonensis* sp. nov.
  8. " *magnus* sp. nov.
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III. List of Scottish Species.
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I. INTRODUCTION.

In a paper published in the Geological Magazine last year (LXXIII, 385–412), it was mentioned that in my collection of Scottish Carboniferous crinoids there remained ten or eleven species to be described. In the present paper eleven species are dealt with, but I find this does not complete the list since there are still a few others, including species of *Hydreionocrinus*, *Eupachycrinus*, etc., and some very minute forms belonging to unknown genera which require further elucidation. It is my hope later on to describe these along with a revision of the Scottish Carboniferous crinoids as a whole. Meanwhile, on another page is given a list of all the species known to date so that a comparison can be made with the faunas of other regions. Here, I wish to add to the list of species already given from Coplow Knoll, Clitheroe (C_1) (Geol.

Mag., 1935, LXXII, p. 205), the following species: *Platycrinus coronatus* Goldfuss, *Dichocrinus* sp., *Symbathocrinus conicus* Phillips, and *Mespilocrinus forbesianus* de Koninck & Le Hon.

For the loan of specimens of *Poteriocrinus* and *Rhodocrinus* for study and comparison I have to thank the authorities of the British Museum, especially Mr. L. Bairstow, of the Geological Department, Drs. J. Pringle and C. J. Stubblefield, of the Geological Survey in London, and Mr. D. Balsillie, and his assistant, Mr. Goodlet, of the Geological Department of the Royal Scottish Museum, in Edinburgh.

II. DESCRIPTION OF SPECIES.

DICYCLICA CAMERATA Bather.

RHODOCRINIDAE Roemer

Rhodocrinus Miller.

Rhodocrinus baccatus sp. nov.

Plate XIII, Figs. 1–9; Text-figs. 1 and 2.

Diagnosis.—Calyx subglobose, tending to become constricted towards the top; height about the same or a little less than the width; plates slightly convex, smooth, with ridges at their margins, the elevated portions passing from plate to plate; iBr numerous; arms free from $IIBr_1$; anus excentric, not protuberant.

Holotype.—J. Wright Coll. No. 2312, Plate XIII, Figs. 1, 4, 6 and 7.

Paratypes.—J. Wright Coll. Nos. 2313, 2314, 2315, Plate XIII, Figs. 5, 2 and 3. One specimen in Dunlop Coll., Plate XIII, Fig. 9.

Localities.—No. 1 Bed, Invertiel, Seafield Tower Limestone, Roscobie, Ardross, all in Fife; Beith, Ayrshire; Harelawhill, Liddesdale.

Remarks.

I have examined a considerable number of specimens of *Rhodocrinus* from Scottish Lower Carboniferous rocks all of which appear to belong to the present species. Among these are fifty-seven specimens from No. 1 Bed, Invertiel, three from the Seafield Tower Limestone near Kirkcaldy, three from the Ardross Limestone near Elie, five from Roscobie, and four from Harelawhill Quarry, Liddesdale, all in my collection. I have also examined three specimens from Beith, Ayrshire, in the collection of the late Robert Dunlop in the Royal Scottish Museum, Edinburgh, and three specimens in the Geological Survey collection in the same institution. One of the Survey specimens is from Brunston, Penicuik, Midlothian, registered no. 1552, the other two are from Crichton Quarry, Pathhead, Midlothian, and numbered 1553 and 1554. Besides these I have seen a few specimens in the J. Neilson collection in the Royal Scottish Museum and in that of J. Smith in the Geological Survey collection at Southpark, Edinburgh. I have also had the privilege of examining certain specimens belonging to the Geological Department of the British Museum. These include ten more or less crushed and fragmentary calices from the Yoredale Series of Far House Barn, Cam Beck, Yorkshire (E 26005–14) which, so far as can be judged from their condition, seem to differ little from the other Scottish specimens unless in the smoother character of their plates. Also included in the British Museum material are four specimens, two of which are from Clevedon Bay, Somerset, queried as *R. verus* Miller, one crushed calyx from Press's Quarry, Bristol, unnamed, and one incomplete broken calyx from the Carboniferous Limestone of Cork, Ireland, labelled *R. ? uniarticulatus* de Koninck & Le Hon. All four specimens are different from the Scottish and Yorkshire specimens mentioned above.

The occurrence of the genus *Rhodocrinus* in Scottish Lower Carboniferous rocks has been known for a long time. As far back as 1840 the Rev. J. Anderson, of Newburgh, in Leighton's *History of Fife*, lists *R. verus* Miller from Invertiel. The specimens of this and other species collected by Mr. Anderson in Fife appear to have been lost, but in all probability his *R. verus* is the same as the species now to be discussed. Another early Fife record is that of the Rev. T. Brown, who mentions *Rhodocrinus* from his bed "L" but does not give any specific name or locality (1860, p. 398). In the West of Scotland, *R. uniarticulatus* de Koninck & Le Hon. is recorded by Armstrong & Young from Beith Quarries (1876, p. 42), and the species is again listed by J. Smith from the same locality (1904, p. 509). I have seen most of the specimens from the West of Scotland and the example from Beith in the Dunlop collection now shown on Plate XIII, Fig. 9, is typical. These specimens certainly do not belong to *R. uniarticulatus*, which to the best of my knowledge has not been found in the Scottish Lower Carboniferous limestones. In records given by myself, the specimen referred to *R.* cf. *uniarticulatus* de Koninck & Le Hon proves on further cleaning to be a rather squeezed example of the prevailing species here described. All my other specimens have previously been recorded as *Rhodocrinus* No. 1 sp.

In dealing with the Scottish specimens, the chief difficulty is that the great majority, especially those found at Invertiel and elsewhere, are much flattened and distorted and unless one can see the interbrachial areas clearly they might easily be confounded with *R. uniarticulatus*, which has a comparatively low or compressed calyx (1854, de Koninck & Le Hon, pl. i, fig. 13, and 1930, W. E. Schmidt, pl. ii, figs. 1 and 2). In such specimens as those from Beith, however, and in several quite round and solid examples from Invertiel the character of our new species is seen to advantage and when the plates are analysed is found to be altogether different from *R. uniarticulatus*, with which, especially in the West of Scotland, it has been confused for so many years. Like de Koninck & Le Hon's and W. E. Schmidt's specimens of *R. uniarticulatus*, none of the Scottish specimens have any part of the free arms in position, so that distinctions have to be made from the general shape of the calyx and the plates composing it. The photographs on Pl. XIII, Figs. 1–9, and Text-figs. 1 and 2 give a good idea of the aspect of the calyx in the new species. Viewed from below the infrabasals are entirely hidden by the column and sunk in a deep concavity with very steep or straight sides. The basals are conspicuous and the lower part of the calyx is rather flat with the basals and part of the radials and interradials invisible in a side view. The calyx swells out to its widest diameter about the position of the first primibrachs after which it tends to become constricted towards the top. This is almost an invariable rule, although in a few cases the width at the top, which is taken at about the level of the free arm bases, i.e. a little above the first secundibrachs is nearly the same as the width below. The following measurements are typical:—

Holotype, J. W. Coll. No. 2312, Pl. XIII, Figs. 1, 4, 6 and 7:—

Height of calyx over all	15·4 mm.
Width laterally	17 ,,
,, ant. to post.	15·6 ,,
,, at top	16 ,,

Paratype, J. W. Coll. No. 2314, Pl. XIII, Fig. 2:—

Height of calyx over all	12 mm.
Width laterally	11·6 ,,
,, ant. to post.	11·4 ,,
,, at top	9·6 ,,

Paratype, J. W. Coll. No. 2315, Pl. XIII, Fig. 3:—

Height of calyx over all	10·5 mm.
Width laterally	10·5 ,,
,, ant. to post.	10·6 ,,
,, at top	7·6 ,,

J. W. Coll. No. 2316*a*:—

Height of calyx over all	13·5 mm.
Width laterally	13·5 ,,
,, ant. to post.	13·3 ,,
,, at top	10 ,,

R. Dunlop specimen, Pl. XIII, Fig. 9:—

Height of calyx over all	17 mm.
Width laterally	19 ,,
,, ant. to post.	18 ,,
,, at top	16·3 ,,

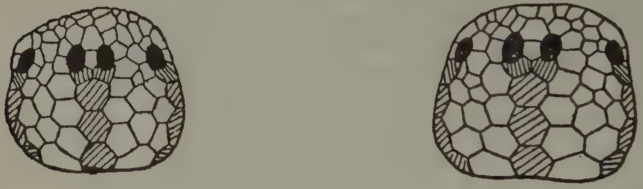
Geological Survey specimens:—

No. 1552.	
Height of calyx over all	14·4 mm.
Width laterally	14·4 ,,
No. 1553.	
Height of calyx over all	17 mm.
Width laterally	18 ,,
No. 1554.	
Height of calyx over all	13·7 mm.
Width laterally	14 ,,

In the three Geological Survey specimens the overall width is about the same at top and bottom of the calyx. This is due to the fact that the brachial series are slightly lobed, i.e. instead of the calyx becoming more or less uniformly constricted in an upward direction, the brachials are nearly vertical up to the position of the first secundibrachs and stand out from the interbrachial areas rather more prominently than is usual in the other specimens. This gives a somewhat special character to these calices and at first it seemed possible they belonged to another species. Other than this slight difference in habitus, however, there is nothing distinctive enough to separate them from the other specimens. One of the small specimens, No. 1552, differs only in having two ranges of plates in the interbrachial areas instead of the usual three of No. 1553. The third specimen, No. 1554, is too badly preserved for minute examination.

As regards the plates in general, in well-preserved specimens they are on the whole slightly convex without any surface ornamentation, but at the margins they are flexed or ridged, the elevated portions passing across the sutures from plate to plate with little depressions between (Pl. XIII, Figs. 1–9). In this character they are not unlike some American species, e.g. *R. nanus* Meek & Worthen, *R. kirkbyi* Wachsmuth & Springer and *R. douglassi* Miller & Gurley, but the general shape of the calyx in these species seems to be different (Wachsmuth & Springer, 1897, pl. xii, figs. 1 and 2; Laundon, 1933, pl. i, figs. 7–15). The ridging of the plates in our species is not developed to anything like the same extent as in *R. verus* Miller, or in *R. verisimilis* Grenfell, which is stated to have plates of the same character (Grenfell, 1876, pl. vii, figs. 6–10, p. 482). In our specimens it is often difficult to detect the suture lines between the plates as the hollows between the ridges may be filled with shale and in the case of the Invertiel and Beith specimens, when this matrix is black and the plates are lighter in colour a characteristic stellated appearance is given to the plates as a whole. In many other specimens this character is not so pronounced, the suture lines being quite distinct and the plates are smooth and flush with one another. Slight traces of the ridging can usually be seen here and there but is not evident in the Yoredale specimens, B.M. E 26005–14, which are practically smooth all over. In this respect these specimens resemble the American species *R. watersianus* Wachsmuth & Springer or even the Belgian *R. uniarticulatus* de Koninck & Le Hon, both of which appear to have smooth plates, but have a fewer number of interbrachials. In the rather unsatisfactory condition of the Yorkshire specimens, however, all of which are flattened or fragmentary, it is impossible to determine the true contour of the calyx and I find it difficult to decide whether they belong to a distinct species. Possibly the greater smoothness of their plates is in part due to conditions of deposition since the shaly matrix here is much less calcareous than that associated with any of the Scottish specimens. Otherwise, as to number of interbrachials, etc., the Yorkshire specimens differ little or not at all from the Scottish specimens already mentioned.

As regards the chief differences between all our specimens and *R. uniarticulatus* de Koninck & Le Hon, the nearest and probably best known European species with which they can be compared, the first point that strikes one is the greater height of the calyx in our species. This is correlated with an increased number of plates in the interbrachial areas. In *R. uniarticulatus* these areas are occupied by five or six plates only, the first interbrachial being succeeded by two large plates upon which are two smaller plates lying about the level of the first secundibrachs. In our species the interbrachials number as many as eleven or twelve up to the same level. I have examined all the specimens to see if there is any difference in the relative position of these plates and find there are two main plans in their arrangement. This applies specially to the lower ranges. For example, in the holotype, in three of the interradii the first interbrachial is truncated at the top and supports another plate about the same size directly in contact with it. It also has a truncated top and is succeeded by another plate of nearly the same size which in turn has a smaller plate surmounting it. We thus have a vertical series of plates in the middle of the area. Adjoining this row on either side are other plates linking the middle series to the brachials. This arrangement (Text-fig. 1) seems to be irregular and is called so for purposes of classification. In the other two interradii the arrangement is like that of Text-fig. 2, where the first interbrachial is not truncated at the top but has two plates resting on its left and right upper shoulders and so dividing it from the second interbrachial of the middle series. This appears to be the more regular arrangement as in many specimens all the interbrachial areas with the exception of the posterior may be of this



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TEXT-FIGS. 1 and 2.—*Rhodocrinus baccatus* sp. nov. Fig. 1, the holotype from No. 1 Bed, Invertiel; the two interbrachial areas here are of the "irregular" type. Fig. 2, specimen from Beith in the Dunlop collection; the interbrachial areas here are of the "regular" type. × 1½.

character. In such cases the posterior is like that of one of the areas of Text-fig. 1. In American species this seems to be almost an invariable rule (Wachsmuth & Springer, 1897, p. 219), but is not so in the Scottish species as the following statistics show. How far it applies to other species like *R. verus* or *R. verisimilis* is not at present known. In flattened specimens it is of course not possible to see the areas all round the calyx, but from the positions that can be examined, the Invertiel specimens seem to be rather more variable in this respect than those from Beith or from the Yoredale series of Yorkshire. In considering this, however, one must make due allowance for the larger number of specimens from the former locality.

Holotype.—J. W. Coll. No. 2312, all areas irregular except post. and right post.

J. W. Coll. No. 2313, all regular except post.

J. W. Coll. No. 2314, all regular except post. and right post.

J. W. Coll. No. 2615, all regular except post.

J. W. Coll. No. 2316*a*, all irregular except right post. and right ant. lat.

J. W. Coll No. 2316*b*, post. and left ant. lat. irregular, right post. regular, others doubtful.

All from No. 1 Bed Invertiel.

R. Dunlop Coll., two specimens, all areas regular except post. One specimen, three areas regular, other two irregular, positions not ascertained. From Beith, Ayrshire.

British Museum specimens from the Yoredale Series, E 26010, 26011, 26014, one area irregular probably posterior, others regular.

Scottish Geological Survey specimens from Midlothian, No. 1552, two regular areas, others irregular. No. 1553, all irregular except right post. and left ant. lat.

ADUNATA Bather

PLATYCRINIDAE Roemer

Platycrinus Miller

Platycrinus conglobatus sp. nov.

Plate XIII, Figs. 13, 14; Plate XIV, Figs. 8, 9 and 10;
Text-fig. 3.

Platycrinus sp., J. Wright, 1912, pl. v, figs. 4 and 6.
Platycrinus sp., J. Wright, 1914, pl. xviii, fig. 11.
Platycrinus No. 1 sp., J. Wright, 1918, p. 375.

Diagnosis.—Calyx about as wide as high; dorsal cup bowl-shaped; basal circlet rather flat, with slight concave depression near column facet which is slightly excavated; plates of cup faintly grooved at margins in mature specimens; tegmen low, about the same height as cup, flat on top, and composed of numerous plates;

anal opening excentric, not protruding; plates of cup and tegmen smooth without ornamentation.

Holotype.—J. Wright Coll. No. 2053, Plate XIII, Fig. 13.

Paratypes.—J. Wright Coll. Nos. 2054, 2055 *a—m*.

Localities.—No. 1 Bed, Invertiel, Seafield Tower Limestone, Roscobie, Duloch, Cowdens, all in Fife; Carlops, Peeblesshire; Oxwell Mains, East Lothian.

Horizon.—Lower Limestone Group.

Dimensions of Holotype.—Height of calyx over all 18·7 mm.; width between i Amb. 17·4 mm.; height of cup to highest point on radials 9·3 mm.

Dimensions of Paratype No. 2054.—Height of calyx over all 13·5 mm.; width between i Amb. 13·5 mm.; height of dorsal cup to highest point on radials 6·4 mm.

Platycrinus crassiconus sp. nov.

Plate XIII, Figs. 15 and 16; Plate XV, Fig. 15; Text-fig. 4

Platycrinus sp., J. Wright, 1912, pl. v, fig. 5.
Platycrinus sp., J. Wright, 1914, pl. xviii, fig. 9.
Platycrinus No. 2 sp., J. Wright, 1918, p. 375.

Diagnosis.—Dorsal cup more elongated than in previous species; basal circlet conical; tegmen low; anal opening excentric; plates smooth.

Holotype.—J. Wright Coll. No. 2056*a*, Plate XIII, Figs. 15 and 16.

Paratypes.—J. Wright Coll. Nos. 2056 *b—e*.

Localities.—No. 1 Bed, Invertiel, Seafield Tower Limestone, Roscobie, Duloch, all in Fife; Carlops, Peeblesshire.

Platycrinus spiniger sp. nov.

Plate XIII, Fig. 17; Text-figs. 5 and 6.

Platycrinus No. 3 sp., J. Wright, 1918, p. 375.

Diagnosis.—Dorsal cup as in *P. crassiconus* but bearing spines in five lines radiating from column facet to margin of basal circlet, on radials the lines converge to a point below radial facets; columnals also spiniferous.

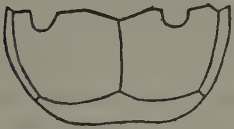
Holotype.—J. Wright Coll. No. 709, Plate XIII, Fig. 17.

Localities.—Roscobie, No. 1 Bed, Invertiel, Seafield Tower Limestone, Duloch, all in Fife; Carlops, Peeblesshire; Oxwell Mains, near Dunbar, East Lothian.

Remarks.

The genus *Platycrinus* is represented in my collection from the Scottish Lower Carboniferous limestones by a large number of specimens which have hitherto been recorded as Nos. 1, 2 and 3 spp.

These are now referred respectively to the species here designated *P. conglobatus*, *P. crassiconus* and *P. spiniger*. The great majority of the specimens are from No. 1 Bed, Invertiel, and the corresponding bed in the Seafield Tower Limestone on the shore between Kirkcaldy and Kinghorn. *P. conglobatus* and *P. crassiconus* occur at Invertiel abundantly and are preserved as complete calices, dorsal cups or detached plates of cup and tegmen. *P. spiniger* is a rare form and is recognizable as cup plates only. None of the specimens has been found with any part of the arms in position; in fact, I have not seen a single specimen of *Platycrinus* from any Scottish locality with the arms preserved, so that our knowledge of the species is derived solely from the calices and plates. Besides the three species mentioned there is possibly another one in the collection but the specimens consist of basal circlets only and cannot be adequately discussed at present.



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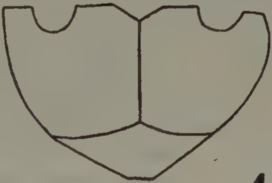

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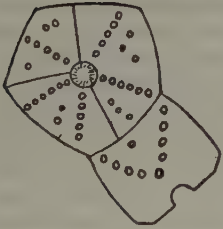

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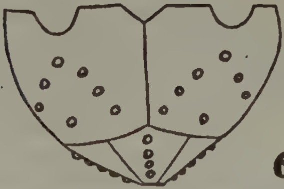

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Text-fig. 3.—*Platycrinus conglobatus* sp. nov., outline of dorsal cup. Fig. 4, *Platycrinus crassiconus* sp. nov., outline of dorsal cup. Fig. 5, *Platycrinus spiniger* sp. nov., basal circlet and radial. Fig. 6, *Platycrinus spiniger* sp. nov., outline of dorsal cup. × 1½.

As to the condition of the specimens, *P. conglobatus* is occasionally found at Invertiel and Seafield quite solid and uncrushed with cup and tegmen intact and I have ninety specimens from the former locality in this state of preservation. These specimens are of all sizes and range from small individuals measuring only 8 mm. in overall height to large examples over 28 mm. in height. The holotype is a medium-sized specimen 18·7 mm. in height. Well preserved specimens like these are, however, comparatively rare and it is more usual to find crushed and distorted examples belonging either to *P. conglobatus* or *P. crassiconus* but from their condition it is often very difficult to determine to which of these species they belong. It is a curious circumstance that among hundreds of specimens of both species the calyx of *P. crassiconus*, unlike that of *P. conglobatus*, has never been found quite round and solid. The dorsal cup, however, is often preserved uncrushed and is easily distinguished from *P. conglobatus* by its more conical basal circlet. Many complete calices of *P. crassiconus* are found at Invertiel with the tegmen in position, but this structure is usually squeezed down on the inner surface of the dorsal cup and so the outline of the complete calyx in this species is not so well known as in *P. conglobatus*. The tegmen, however, appears to have been of a comparatively low nature, not much if any different from that of *P. conglobatus* and as in that species composed of numerous plates. (Plate XIII, Figs. 15 and 16; and Plate XV, Fig. 15.) From the large number of specimens of both species in my collection it is my hope at some future date to work out the growth stages of the tegmenal plates and with this end in view I have sorted out for cleaning a series of the better preserved examples. Meanwhile it may be briefly stated that the calyx of *P. conglobatus* is in outline somewhat rounded and globular; the basal circlet tends to be rather flat; the tegmen is about the same height as the dorsal cup and composed of many plates which increase in number in the larger specimens; the anal opening is excentric and there is no elongated anal tube or protuberance as in many English and Irish species. *P. crassiconus* resembles *P. conglobatus* as to tegmen and other characters, but differs in the shape of the cup. This is specially emphasized by the character of the basal circlet even in very small specimens. Both species have smooth plates with no traces of ornamentation.

P. spiniger is only known to me from detached basal circlets and odd radials. The shape of the cup in this species is similar to that of *P. crassiconus* but the plates are very characteristic, being always studded with what at first look like tubercles, but are really the stumps or broken ends of spines. Their most noticeable feature is that they radiate in five main lines from the vicinity of the column facet to near the sutures of the basals and radials; from the radials they converge to a position a little below the radial facets. Occasionally an odd spine or two may be seen between. Many detached spiniferous columnals are found associated with these plates, often lying alongside, and it is reasonable to conclude that they belong to the column of the same species (Plate XIII, Fig. 17).

Professor Wanner (1916) has revived with some emendations the Austins' name *Pleurocrinus* for species in which, among other characters, the anal opening is situated in the lateral position directly above the right and left posterior radials. *P. conglobatus* and *P. crassiconus* have typical *Platycrinus* tegmens in that the anal opening is on the upper surface in the usual excentric position. *P. spiniger* is here provisionally referred to *Platycrinus*, although nothing is known of its tegmen. Several species from the Carboniferous of England and at least one from the Isle of Man have the anal opening in the lateral position. A study of some new forms is in progress, and it is hoped to publish the results shortly.

Platycrinus cf. *laevis* Miller is recorded by the Survey from Carlops (1910, p. 389); *Platycrinus laevis* Miller is also recorded by Armstrong & Young from Corrieburn and Beith (1876, p. 42) and by J. Smith from Klisyth and Dalry (1904, p. 509). I have seen most of the specimens which consist of basal circlets and radials with smooth plates and they probably belong either to *P. conglobatus* or *P. crassiconus*. *P. conglobatus* has a cup not unlike that of *P. laevis* but the latter species is supposed to have a long anal tube. Miller's original figure (1821, pl. opposite p. 74) does not show this tube, but both the Austins (1843–8, pl. i, fig. 1) and de Koninck & Le Hon (1854, pl. vi, fig. 1) figure specimens with prominent anal tubes which they apparently consider to be well authenticated examples of the species. I have collected several specimens at Hook Head, Ireland, which evidently belong to this species and all show this structure. I have never seen any specimens with an extended anal tube in the Scottish rocks, so that I think the records of *P. laevis* may be ruled out at present.

Platycrinus trigintidactylus Austin is also recorded by the Survey (1900, p. 223), Armstrong & Young (1876, p. 42), and J. Smith (1904, p. 509) from various Scottish localities. I think this species must also be deleted from our Scottish lists. In nearly every case the name has been given to fragments of biserial arms which I am convinced from their structure and size do not belong to any species of *Platycrinus* but are probably fragments of the arms of a species of *Hydreionocrinus* which is common in the Scottish Carboniferous limestones.

In the general shape of the calyx *P. conglobatus* and *P. crassiconus* have certain resemblances to some American species figured by Wachsmuth & Springer (1897, pls. lxix and lxxi), but comparison here is difficult since most of the American forms have the arms in position. At the same time none of the cups or the tegmenal features thereof appear to agree in any way with the Scottish species. *P. crassiconus* is not unlike *P. pileatus* Goldfuss, particularly in the shape of the cup, which is conical, but the tegmen in the Scottish species consists of plates which are quite smooth without tubercles as in *P. pileatus*. Our three species do not agree with any species of *Platycrinus* figured by Miller (1821), the Austins (1843–9) and de Koninck & Le Hon (1854), nor with any specimens I have collected from the limestones of Lancashire, Yorkshire, Ireland or the Isle of Man. *P. crassiconus* comes very close to an undescribed species which I have found at Knoll Wood, Newton in Bolland, Yorkshire.

HEXACRINIDAE Wachsmuth & Springer.

Camptocrinus Wachsmuth & Springer.

Camptocrinus compressus sp. nov.

Plate XIV, Fig. 7; Plate XV, Figs. 2–9, 11, 12 and 14.

During the last few years, in washings of shale from Carlops I have occasionally found stem fragments and columnals quite new to me. Recently a few better preserved examples turned up and on closer examination they prove to belong to *Camptocrinus*, a genus which in Europe has only previously been recorded from the Permo-Carboniferous of the Urals (Yakovlev, 1927, pl. vi, figs. 19, 19 *a–e*; 1930, pl. i, fig. 4). The species seems new since the columnals, although bearing a strong resemblance to the Russian specimens, are more compressed in section and are associated with cups with smooth plates which are clearly different from the Russian cup figured. Our columnals also seem to be different from those of *C. indoaustralicus* Wanner from the Permian of Timor (Wanner, 1924, pl. iii, figs. 9 and 10; Ehrenberg, 1926, pp. 252–3). Among American forms they come nearest to *C. multicirrus* Springer (1926, pl. viii, fig. 6*a*) from the Mississippian (Chester) of Alabama and Illinois, but ours are narrower and more elongated in section. On Plate XV are shown some of the columnals and fragments twice the natural size. Figures 2 and 11 represent two columnals without cirri; Figs. 5, 6 and 12 are cirriferous columnals; Fig. 3 shows a fragment of column from the outer surface with the cirri just showing on the under sides; Fig. 9 is a side view of a fragment with cirriferous columnals separated by others, usually two, which bore no cirri, and Fig. 4 is a fragment in which the cirri on the columnals continue over the outer surface. Fig. 9 of this plate is better compared with Fig. 7 of Plate XIV which shows the same specimen from the inner surface. The columnals here are more distinctly seen. Fig. 14 (Plate XV) shows the columnals natural size.

Along with these fragments and columnals at Carlops occur many bisected basal circlets belonging to cups which I had previously regarded as a species of *Dichocrinus*. The chief difference between this genus and *Camptocrinus* is in the character of the column, the cups being very similar and as detached specimens scarcely distinguishable (Springer, 1926, p. 25). In *Dichocrinus* the column appears to be more or less round throughout and not coiled as in *Camptocrinus* where it is bilateral and crescentic in section. Since the column fragments found at Carlops are associated with so many of these basal circlets it seems reasonable to conclude that they belong to cups of the same species. A similar species occurs at No. 1 Bed, Invertiel, in the form of a few basal circlets and complete cups, but such specimens are very rare and I must say that compressed columnals of the Carlops type have not so far been noticed here in any number. I am, however, figuring a cup from Invertiel which is better preserved than any from Carlops and probably belongs to the same species, Plate XV, Fig. 8.

DICYCLICA INADUNATA Bather
DENDROCRINOIDEA Bather.
POTERIOCRINIDAE (emend. Wachsmuth & Springer).
POTERIOCRININAE Springer.
Poteriocrinus Miller.
Poteriocrinus scotocarbonarius sp. nov.

Plate XIII, Figs. 10, 11 and 12; Plate XIV, Figs. 1–5; Plate XV, Figs. 10 and 13; Plate XVI, Figs. 1, 3 and 7; Text-figs. 7–9.

? *Poteriocrinus* sp., J. Wright, 1914, pl. xx, fig. 7.

Poteriocrinus near *P. plicatus* Austin, J. Wright, 1918, pl. xv, fig. 3.

Poteriocrinus plicatus Austin, *P.* cf. *plicatus* Austin, *P. crassus* Miller (in de Koninck & Le Hon), J. Wright, 1935, p. 207.

Diagnosis.—A large species; cup wider than high; IBB and BB about the same height; RR about half as high as BB; R facets occupying full width of RR, surfaces only slightly hollowed out, striated transversely and with no cross ridge; plates of cup thick and swollen, with deep indentations or grooves along sutures; ornamentation coarse, vermiculate rugose or granular; primibrachs six or more, irregular and interlocking; IBr_1 and IBr_2 usually very thin; column alternating in proximal region.

Holotype.—J. Wright Coll. No. 2283 from Roscobie, Plate XIV, Fig. 5.

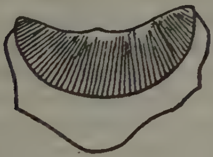
Paratypes.—J. Wright Coll. No. 2286, Plate XIII, Fig. 10; No. 2284, Plate XIII, Figs. 11 and 12; No. 2285, Plate XIV, Figs. 3 and 4; No. 2287, Plate XV, Fig. 10, all from Roscobie; No. 2288, Plate XV, Fig. 13, from No. 1 Bed, Invertiel.

Horizon.—Lower Limestone Group.

Remarks.

This species is represented in my collection by thirty cups of which twenty-seven are from Roscobie, two from No. 1 Bed Invertiel, one from Clattering Well, Bishop Hill, and one from the Seafield Tower Limestone near Kirkcaldy; also included are fifty-three detached infrabasal, basal and radial plates and arm fragments from Roscobie. I am indebted to Mr. F. W. Anderson, of the Scottish Geological Survey, for the loan of the largest cup, shown on Plate XIV, Fig. 1. This specimen belonged to the private collection of the late James Bennie and was collected by him at Roscobie in 1895. Unfortunately, for some reason, the top of the cup has been polished so that the finer details of the radial facets have been obliterated. There is, however, no reason to suppose that these structures were different in this specimen. I have also to thank Mr. D. Balsillie, Keeper of the Geological Department of the Royal Scottish Museum, and his assistant, Mr. Goodlet, for the loan of the cup from the Neilson collection shown on Plate XVI, Fig. 1.

Although the cups vary considerably in size, they have so many features in common that there seems no doubt they all belong to the same species. The smallest well-preserved cup is that shown on Plate XV, Fig. 13. It is less than 15 mm. in height and from this there is a somewhat graduated series up to the largest cup, shown on Plate XIV, Fig. 1, which is over 36 mm. in height. The chief characteristics of the cups are the swollen and thick nature of the plates, the deep indentations or furrows along the sutures and the very coarse ornamentation on the plates. This last is for the most part of a vermiculate rugose nature, occasionally it is more granular and is better preserved on some cups than on others; for example, on the large specimen on Plate XIV, Fig. 1, it is nearly all worn off since this cup is much weathered, but it is shown to perfection on the specimen on Plate XIV, Fig. 5, which is taken as the holotype. Though somewhat flattened this specimen exhibits all the characters of the cup plates and several of the primibrachs perhaps better than any other. Most of the cups are slightly squeezed, but on Plate XIII, Figs. 11 and 12, are shown two views of a medium sized example which give a good idea of the rotundity of the cups in an uncrushed condition. The plates in this specimen are, however, rather worn and only show traces of the ornamentation here and there. It may be noticed from this and other figures that the infrabasals are high and prominent and about the same height as the basals. The radials are comparatively low but on most cups they look higher because one to three or more of the primibrachs are in position. In most cases these primibrachs are exceedingly thin, especially the first primibrach, and so closely are they fitted together, that it is sometimes difficult to detect the line of junction with the radial or those above. The low nature and width of the radials can be seen on Plate XIII, Fig. 10, where the radial on left centre of photograph has no primibrach attached. The radial immediately to the right has a short or very thin primibrach in position. The specimen on Plate XIII, Fig. 11, also has no primibrachs in position. These are somewhat exceptional cases. The specimen on Plate XIV, Fig. 1, shows the low nature of the radials well and this may also be observed in the holotype, Plate XIV, Fig. 5, where, however, one must make allowance for the primibrachs still in position. Actually the facets on the radials are only well seen in a few cups and on the detached radials from Roscobie. The area occupied by these facets is wide and covers almost all the upper surface of the radials. It is not greatly hollowed out or narrow as in a typical *Poteriocrinus* and there is no indication of a cross ridge; instead we have a series of striations which cut across and occupy the whole of the surface from the outer border inwards (Text-figs. 7–9). This is also the type of articulation on the joint faces of the primibrachs and higher brachials. The specimen on Plate XV, Fig. 10, is somewhat flattened, but it shows specially well the width and shape of the radials and joint faces of the primibrachs. There is also a single interbrachial in place here and this can be seen between the left and right upper corners of the radials on left of photograph. This is the only instance of the kind noticed in the Fife specimens although I have observed the same thing in several specimens of *Poteriocrinus* from the Clitheroe region. The radial on the left here has a very thin primibrach attached and the adjoining radial has two primibrachs. A curious feature which is noticeable on the holotype and on other specimens is not only the generally thin nature of the first and second primibrachs, but the extreme irregularity in thickness of those above and the way in which they thicken or thin out and interlock with one another. This arrangement is not confined to the primibrachs only, but is noticeable on fragments of arms with axillaries and branching portions, representing higher parts of the arms, thus indicating that the arms generally were of this nature. Though in most cases when a cup is viewed from the side the outline of the top of each radial is straight occasionally it is quite sinuous and sometimes the joint faces of the primibrachs are of the same character. This can be seen in the right ray of the holotype. Both rays here show the irregularities of the primibrachs. The branching



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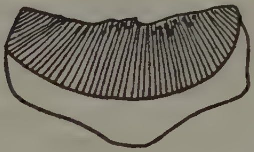

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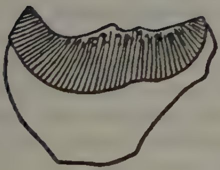

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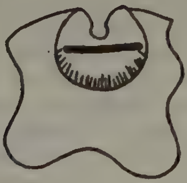

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Text-figs. 7, 8, and 9.—*Poteriocrinus scotocarbonarius* sp. nov., radials with striated facets from Roscobie. Fig. 10, a typical radial from Tournai, Belgium, probably belonging to *P. plicatus* Austin or *P. crassus* Miller (*non* de Koninck and Le Hon). × 1½.

and extent of the arms is unknown and the number of primibrachs before any branching took place is not evident on any specimen. In the holotype six primibrachs can be counted on the left ray and this is the largest number so far seen. No trace of the ventral sac has been found with any of the specimens. The anal area is wide but it is not usually well preserved (Plate XIV, Fig. 4). The arrangement of the anal plates here and in all specimens where it can be examined is of the normal type, i.e. with RA, anal X and rt usually within the limits of the cup but there are variations in the relative sizes of the plates. The column is not known for any length. Generally most cups have a few columnals still adherent. In the holotype the first two columnals are very thin with crenulated edges and approximately of the same thickness. The third is much thicker and wider. It tapers somewhat from the level of the thin columnals and round the periphery it is serrated or nodular. This may be noted on Plate XIV, Fig. 5, but below this point the specimen is damaged. Other specimens show that in general the proximal region of the column is of an alternating character, thick columnals like the one mentioned being separated by two or possibly three or more very thin ones. The medium-sized specimen on Plate XIV, Fig. 2, indicates this and on Plate XVI, Fig. 3, is shown a fragment of this type of column which is easily recognized and common at Roscobie. It is characterized by the same type of ornamentation as the cup and arms. What the nature of the column was lower down is a matter for speculation. Considering that the diameter of this fragment is about one inch, it may have reached a length of three or four feet and would no doubt alter considerably in that distance. (I have measured a long continuous column—incomplete at both ends—in the matrix of one of the limestones of the Seafield shore which was roughly $\frac{3}{4}$–1 inch in diameter, over 30 inches long, and of the *P. crassus* type, i.e., its segments resembled the figures given by Miller and the Austins for portions of the column of that species. Being abraded other details could not be ascertained.)

Relationship with other Species

There can be no doubt that our cups have certain resemblances to the two English species *P. crassus* Miller and *P. plicatus* Austin, and in fact till recently several of the cups have been regarded as belonging to one or the other of these species. The present examination, however, has convinced me that there are important differences in the Fife cups which clearly show that they belong to a distinct species. At the same time it has to be admitted that we know little about the main characters of the two species mentioned and comparisons can only be made from the rather unsatisfactory figures and descriptions of Miller (1821), the Austins (1843–9) and de Koninck & Le Hon (1854). So far as Scottish Geological Survey and West of Scotland records are concerned the name *P. crassus* seems to have been given somewhat indiscriminately to column fragments or ossicles supposed to have some resemblance to those figured by Miller. No cups similar to those here noted appear to have been found. Although interesting in themselves these records are of little value in the present investigation. So far as I know the name *P. plicatus* has not been recorded by the Survey.

At first sight a medium-sized cup like that shown on Plate XIV, Figs. 3 and 4, might readily be taken for *P. plicatus* Austin since it has a resemblance to the figure of that species given by the Austins (1843–9, pl. ix, figs. 4 *a–c*) or later by de Koninck & Le Hon in their Belgian work (1854, pl. i, fig. 11). Again, some cups have a general resemblance to the figures of *P. crassus* as given by de Koninck & Le Hon (pl. i, figs. 10 *c* and *d*) but not that given by Miller himself when founding the genus (1821, pl. opposite p. 68). This raises the questions, what are the essential characters of *P. crassus* and what is really the difference between it and *P. plicatus* Austin? There is undoubtedly much confusion in this matter. The cup figured by Miller as *P. crassus* is stated by the Austins to be a restoration and this seems to be specially the case in so far as the radial circlet is concerned. The Austins figure Miller's original specimen of *P. crassus* on their pl. viii, 3 *c*. It is said to come from Clevedon Bay, Somerset, and is now in the Bristol Museum where I have seen it, but did not have an opportunity to handle it. The specimen is somewhat worn and not well preserved, but it is clear that the infra-basal circlet is fairly high, the cup generally is elongated and has no marked plications or indentations between the sutures. The area occupied by the radial facets appears rather wide. This is confirmed by the other figure of the species given by the Austins (pl. viii, fig. 3*a*) where, however, portions of the arms are attached to the radials though the facets themselves are not seen. In Miller's drawing (pl. opposite p. 68) radials with plicated or wavy borders and narrow horse-shoe shaped facets with distinct cross ridges are placed in position as well as some detached radials showing the same structure alongside. It would seem to be a question whether these radials really belong to this species. They certainly have little resemblance to the Austins' figures of *P. crassus*. They have in fact more resemblance to the radials of *P. plicatus* as given by the Austins (1843–9, pl. ix, figs. 4 *a–c*) and later by de Koninck & Le Hon (1854, pl. i, fig. 11). Springer, however, accepts such radials as characteristic of the genus *Poteriocrinus* and taking them as typical of *P. crassus* Miller says that *P. plicatus* Austin is probably the same thing (1911, p. 150). Moreover, he also states (op. cit., p. 135) that the specimen and restoration of *P. crassus* Miller given by de Koninck & Le Hon (1854, pl. i, figs. 10 *c* and *d*) may not belong to *Poteriocrinus* because of the structure of the radial facets. In the Belgian specimen the facets are comparatively wide and there is no cross ridge but a series of striations which run across the facets from the outer border inwards. Now, as already indicated, this is the type of articulation on all the Fife cups, on radials and brachials alike, and although the radial facets are relatively wider on our cups, it is perfectly clear that they come nearer to de Koninck & Le Hon's figures of *P. crassus* than they do to those of Miller and the Austins. In fact, the radial facets on our cups have no resemblance whatever to Miller's figured specimens of *P. crassus* which has been taken as the type of the genus. These radial facets are therefore not typical of *Poteriocrinus* as at present understood and it seems possible that a new genus may have to be created for the Fife and Belgian specimens. This question, however, cannot be finally settled without a thorough examination of the type specimens of *P. crassus* Miller and *P. plicatus* Austin and others like them. Meanwhile the following details are from some specimens which I have had on loan from the British Museum.

British Museum Specimens

Labelled *P. crassus* Miller.

E 25972.—A squeezed cup, about 21 mm. in height with twelve columnals still adherent. Column fairly equal in thickness and width with crenulated edges. Specimen greatly worn. Radials wide and not narrow or horse-shoe shaped, but facets poorly preserved or hidden by primibrachs. Joint line between one of the radials and first primibrach crenulated thus indicating that the outer border at least of the facets is striated. General aspect of cup agrees with Miller's and the Austins' figures of *P. crassus*. The name on label therefore seems justified. The plates are not plicated; their surfaces have the appearance of being corroded by the action of the sea or weathering, the result being that all the plates now exhibit peculiar vermiform markings which are not raised but appear as if etched into the surface. How much of this is due to the original ornamentation is not easy to say. The Austins state that the plates of *P. crassus* are granulated. The preservation of this specimen is not good and it has little resemblance to the Fife cups. In colour it is reddish and this seems to be characteristic of all specimens from Clevedon Bay, Somerset.

E 25974–8.—One infrabasal circlet with fourteen rather thin columnals adherent, of uniform width, thinnest next cup. One arm fragment, one basal plate, two radials with plicated borders and one primibrach on each, distinct cross ridge on joint faces. These radials are like Miller's (*non* de Koninck & Le Hon's) figures of *P. crassus* and the Austins' and de Koninck & Le Hon's figures of *P. plicatus*. They have no resemblance whatever to the Fife species or to de Koninck & Le Hon's figures of *P. crassus*. They should probably be named *P. plicatus*. From Tournai, Belgium.

E 5586 *a* and *b*.—Two cups, about 19 mm. and 22 mm. high; radial facets wide, but facet surfaces hidden by primibrachs; very similar to Clitheroe forms and probably from this area; only labelled "Carboniferous Limestone". The name *P. crassus* here seems justified.

Labelled *P. plicatus* Austin.

E 25979.—One cup about 27 mm. high, radial facets hidden by primibrachs; same species as foregoing and should also be grouped with *P. crassus*; from Yorkshire.

E 75844.—Cast of the large specimen with ventral sac, part of arms and column, figured by Grenfell (1875, pl. vi, fig. 1) from Clifton, Bristol. Cup here agrees well with figures of *P. plicatus.*

E 25973.—Cup only, rather worn, same as foregoing; general shape like the Austins' figures of *P. plicatus* but no radial facets preserved. From Clevedon Bay, Somerset.

E 5909.—Small cup somewhat squeezed, similar to preceding, but here also radial facets obscure. From Clifton, Bristol.

E 14360–3.—Two radials with narrow facets, hollowed out and with distinct cross ridge, similar to the two under E 25974–8 which are labelled *P. crassus*, but should probably be placed under *P. plicatus*; borders of plates much plicated. One radial with wide facet, details obscure; one probably belonging to *Pachylocrinus* and not to *Poteriocrinus.* From Tournai, Belgium.

Geological Survey Specimens, labelled *P. plicatus*, Nos. 54429–54430.—One basal plate; one radial with wavy borders, rather small facet but details obscure. Clevedon Bay, Somerset.

In addition to the above I have again examined ten cups from Coplow Knoll, Clitheroe, all of which I have hitherto recorded as *P. crassus* Miller. They are identical with the British Museum specimens noted above (E 5588 *a* and *b* and E 25979 from the Carboniferous Limestone and Yorkshire respectively). In all these English specimens very little trace of the original ornamentation is left. Faint indications can be seen here and there, but it does not seem to have been anything like so coarse as in the Fife cups. As a group the English specimens are also much below the average size of the Fife cups. Unfortunately all the Coplow cups except one have one or more of the primibrachs in position. I have cleaned this cup and exposed three of the radial facets. These are hollowed out and show traces of striations at their outer borders. They also have a distinct cross ridge. This proves that the Lancashire and Yorkshire cups do not belong to the same species as the Fife cups and that in this character they are also different from the Belgian specimen figured as *P. crassus* by de Koninck & Le Hon. Their exact relationship to *P. crassus* Miller and *P. plicatus* Austin is, however, not so clear although we must conclude that they belong to one or the other of these species. On the whole I still incline to place them all under *P. crassus* Miller (*non* de Koninck & Le Hon) rather than under *P. plicatus* Austin since there seems good reason to believe that the latter species differs in the greater plication of the cup plates, a prominent character in the Austins' specimens which evidently induced these authors to create the species. Support is given to this view by the figures published by Grenfell (1875, pl. vi, figs. 1–4) and strengthened by the British Museum specimens noted above (E 75844, E 25973 and E 5909). Grenfell's and the British Museum specimens, although they do not show the radial facets, have cups which are very characteristic and rather different from the Lancashire and Yorkshire forms. Their plates are much plicated and the cups certainly agree far better with the figures of *P. plicatus* given by the Austins and de Koninck & Le Hon than they do with Miller's or the Austins' figures of *P. crassus.* In *P. plicatus,* besides the greater plication of the plates the infrabasal circlet seems to be comparatively low. In the Lancashire and Yorkshire cups here regarded as *P. crassus* Miller, the circlet is moderately high and although always indicated the indentations between the plates are not specially marked, at any rate to the same extent as in the Clifton specimen of Grenfell (British Museum E 75844) or in the British Museum specimens from Clevedon Bay (E 25973 and E 5909). Placing all these specimens together, one has little hesitation in referring the latter to *P. plicatus* Austin and the Lancashire and Yorkshire cups to *P. crassus* Miller. It cannot of course be maintained that this is quite a satisfactory solution of the matter, but under present circumstances there is no other place for them.

One clear fact which has emerged from the present examination is that the Fife cups do not agree with *P. crassus* Miller or *P. plicatus* Austin as figured by their authors; nor do they agree with any of the English specimens here referred to these two species. They come, however, nearer to the Belgian specimen figured as *P. crassus* Miller by de Koninck & Le Hon and are apparently closely related to it. Even so, they differ from it and all the others in the much coarser ornamentation of the plates, the deeper grooves or indentations between the sutures and in the character of the column. They also differ in the character of the arms, at least from the English specimens. This is inferred from the relatively thicker and more regular arrangement of the primibrachs in all the specimens from Bristol, Lancashire and Yorkshire as well as from the figures of the Austins and Grenfell. It seems probable that the Fife specimens agree better with the Belgian forms in this respect, but we have as yet no evidence about this.

Poteriocrinus pentonensis sp. nov.

Plate XIV, Fig. 6.

Diagnosis.—A moderate sized species; IBB about as high as BB, with concave centres; BB tumid; RR about half as high as BB; brachials thick, rounded, not interlocking; IBr thirteen or more; column alternating.

Holotype.—J. Wright Coll. No. 2198.

Locality.—Penton Linns, Liddesdale.

Horizon.—Lower Limestone Group.

Remarks.

This species differs from the preceding in the shape of the infrabasals which are hollowed out or concave in their centres and not uniformly tumid as in *P. scotocarbonarius*. The species also differs in the character of the brachials which are relatively thicker and more rounded and do not interlock. In this respect the arms come nearer to the English forms of *P. crassus* and *P. plicatus* but the plates are heavier with rounded margins not flush as in the English specimens. The ornamentation is if anything coarser than in *P. scotocarbonarius*. The number of primibrachs cannot be definitely fixed, but on the ray on right of photograph the thirteenth primibrach is axillary. The ray in the centre has fifteen and the ray on left has thirteen without sign of branching. The column is preserved for about 3½ inches and is of an alternating character throughout, not unlike that of *P. scotocarbonarius*. The species is represented by one specimen only from Penton Linns.

Poteriocrinus magnus sp. nov.

Plate XV, Fig. 1.

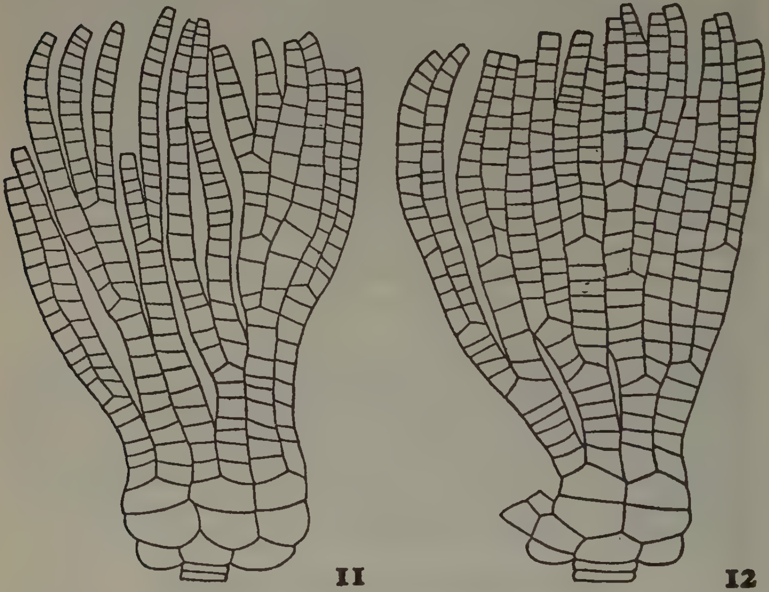
This species seem to have attained a large size, much larger than the two previous species, but is only known to me from detached cup plates. Those figured are from Roscobie but the same species occurs at Invertiel (No. 2 Bed), Seafield Tower, etc. In contrast to *P. scotocarbonarius* the plates of this species are very thin. The radials are characteristic and easily recognized. They have a distinct cross ridge and come nearer to a typical *Poteriocrinus* than either of the preceding species. The plates are quite smooth.

Pachylocrinus Wachsmuth & Springer

Pachylocrinus clavatus sp. nov.

Plate XV, Fig. 16.

This species is represented by one specimen from Roscobie (J. Wright Coll. No. 2500). It consists of a cup, somewhat flattened, with portions of the left posterior, right posterior and right ant. lat. rays. The cup appears to have been shallow with rather thin plates and the anal area is quite normal. In these characters it differs little from other species referred to *Pachylocrinus* but the arm characters do not agree with any species that I can trace. At first I felt inclined to refer the specimen to *Decadocrinus* since in general aspect the arms are not unlike such a species as *Decadocrinus halli* (Hall) (Springer, 1926, pl. xvii, figs. 4 and 5). Although not too clearly seen in the photograph, the eighth secundibrach in the left ramus of right ant. lat. ray is axillary and the tenth secundibrach in the right ramus of right posterior ray is also axillary. The arms therefore branch here so that the specimen is definitely not a *Decadocrinus*. Probably it is best placed under *Pachylocrinus* until we get more information about it. The pinnules in this species are very striking, being as a whole heavy and club-like and much swollen where they join the brachials. A few of the ventral sac plates can be detected between the left and right posterior rays just above the anal plates of the cup, but they are too much displaced to convey any useful information about the sac itself.



Text-figs. 11 and 12.—*Pachylocrinus tyriensis* sp. nov. from No. 3 bed, Invertiel. Drawing of both sides of crown shown on Pl. XVI, Fig. 5. Nat. size.

Pachylocrinus tyriensis sp. nov.

Plate XVI, Figs. 2, 5 and 6; Text-figs. 11 and 12

Diagnosis.—A moderate-sized species; cup shallow bowl-shaped, anal area normal; IBB sunk in deep concavity and invisible in side view; IBr one; IIBr five or six; brachials moderately long with more or less parallel sutures; surface ornamentation vermiform; margins of cup plates flexed; column round.

Holotype.—J. Wright Coll. No. 2265, Plate XVI, Fig. 5.

Paratypes.—J. Wright Coll. Nos. 2266, 2267, 2268, 2269, 2270, 2271.

Localities.—No. 3 Bed, Invertiel, and Roscobie.

Horizon.—Lower Limestone Group.

Remarks.

In referring this species to *Pachylocrinus* I do so with some diffidence. That it belongs to the *Poteriocrininae* there can be no doubt. The cup is somewhat bowl-shaped and the anal area is quite normal. The radial facets agree with *Eupachycrinus*, *Zeacrinus* and allied genera and the cup itself, while having a characteristic appearance due to the flexuous margins of the plates where they join each other, is not markedly dissimilar from that of *Eupachycrinus calyx* (McCoy) unless in the curious somewhat vermiform ornamentation and the generally larger size. The arms of this species, however, give it a special character in that the brachials are unusually long in the distal region of the arms and are heavy, rounded and rather clumsy in appearance. I have only found one fairly complete example of a crown at No. 3 Bed, Invertiel (Plate XVI, Fig. 5); also two detached cups, and six somewhat fragmentary specimens including cups and parts of the arms were obtained at Roscobie.

Aesiocrinus Miller & Gurley.

Aesiocrinus cf. *harii* Miller & Gurley.

Plate XVI, Fig. 4.

The specimen here referred to was found by me many years ago at Penton Linns, Liddesdale. Although rather smaller it seems to come very near to *Aesiocrinus harii* Miller & Gurley which is found in the Upper Coal Measures of Kansas City, U.S.A. (1890, pl. iii, fig. 1). Unfortunately, the cup in our specimen is considerably crushed and I cannot be certain that it is of the same shape and plan as that of Miller & Gurley's species. Springer (1911, p. 145) considers *Aesiocrinus* to be a synonym of *Graphiocrinus*, but I am provisionally retaining the former name since the general appearance of our specimen as it lies on the slab, and the fact that in one ray there can be seen two primibrachs, are highly suggestive of Miller & Gurley's figure. Also rather more than half an inch of the column is attached to the cup and at the end of this portion is a bundle of cirri which appear to have been numerous here. In Miller & Gurley's other species *Aesiocrinus magnificus* (pl. ii, fig. 1) cirri also are numerous about this position. There is no trace of the ventral sac in our specimen.

(III) LIST OF SCOTTISH SPECIES.

Camerata.

(1) *Rhodocrinus baccatus* sp. nov.**

Adunata.

(2) *Platycrinus conglobatus* sp. nov.
(3) „ *crassiconus* sp. nov.
(4) „ *spiniger* sp. nov.
(5) *Camptocrinus compressus* sp. nov.

INADUNATA.

(6) *Poteriocrinus scotocarbonarius* sp. nov.
(7) „ *pentonensis* sp. nov.
(8) „ *magnus* sp. nov.
(9) *Pachylocrinus dunlopi* Wright.
(10) „ *tielensis* Wright.
(11) „ *clavatus* sp. nov.
(12) „ *tyriensis* sp. nov.
(13) *Eupachycrinus calyx* (McCoy).
(14) „ *stellaris* Wright.
(15) „ *ardrossensis* Wright.*
(16) *Zeacrinus konincki* Bather.
(17) *Cromyocrinus geminatus* Trautschold.*
(18) *Ulocrinus globularis* de Koninck.
(19) „ *doliolus* Wright.*
(20) *Woodocrinus liddesdalensis* Wright.
(21) „ *gravis* Wright.
(22) „ *whytei* Wright.
(23) „ cf. *expansus* de Koninck.
(24) *Abrotocrinus angustatus* Wright.*
(25) *Scytalecrinus covensis* Wright.*
(26) „ *arbiglandensis* Wright.
(27) „ *pentonensis* Wright.
(28) *Decadocrinus fifensis* Wright.
(29) *Aesiocrinus* cf. *harii* Miller & Gurley.
(30) *Hydreionocrinus* cf. *woodianus* de Koninck.
(31) *Tribrachiocrinus caledonicus* Wright.
(32) *Allagecrinus austinii* Carpenter & Etheridge.
(33) „ *garpelensis* Wright.
(34) „ *biplex* Wright.
(35) *Kallimorphocrinus scoticus* (Wright).
(36) „ „ var. *contractus* Wright.
(37) „ *elongatus* (Wright).
(38) *Catillocrinus scoticus* Wright.
(39) *Carlopsocrinus bullatus* Wright.

FLEXIBILIA.

(40) *Amphicrinus scoticus* Springer.
(41) *Artichthyocrinus springeri* Wright.
(42) *Synerocrinus incurvus* Trautschold.**
(43) „ *smithi* Wright.
(44) *Onychocrinus pulaskiensis* Miller & Gurley.
(45) „ *wrighti* Springer.
(46) *Wachsmuthicrinus ponderosus* Springer.
(47) *Mespilocrinus* cf. *konincki* Hall.
(48) „ *depressus* Wright.

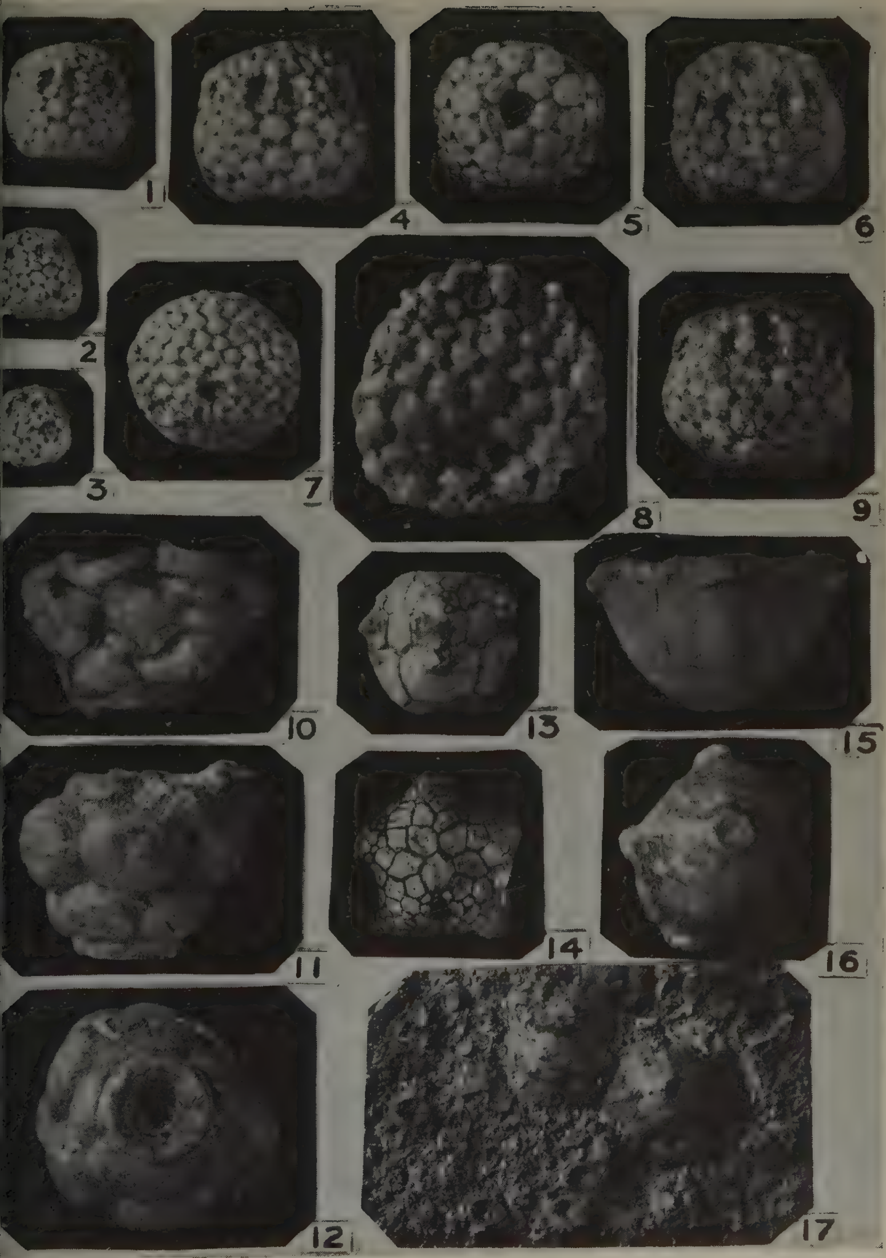
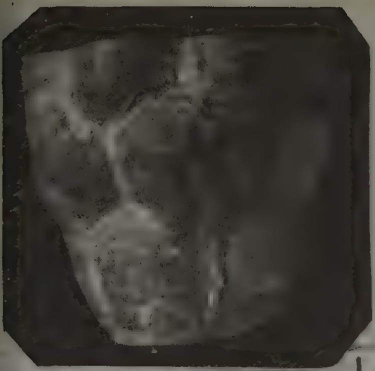


Photo J. Wright.

Scottish Crinoids.

[To face p. 410.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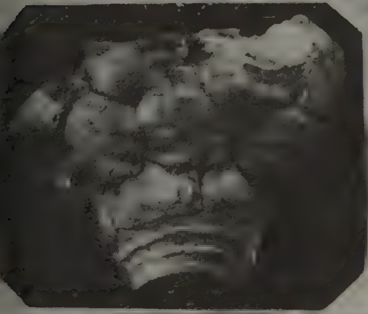
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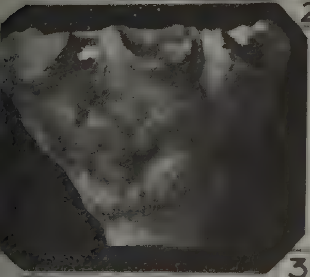
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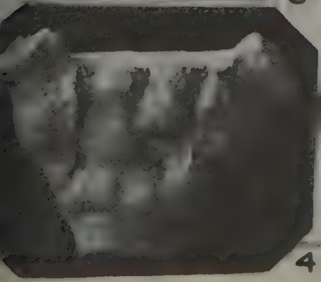
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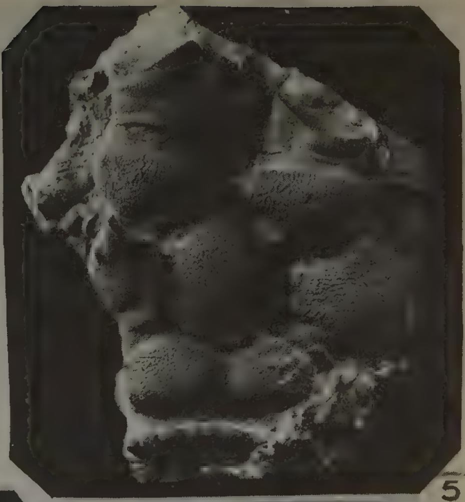
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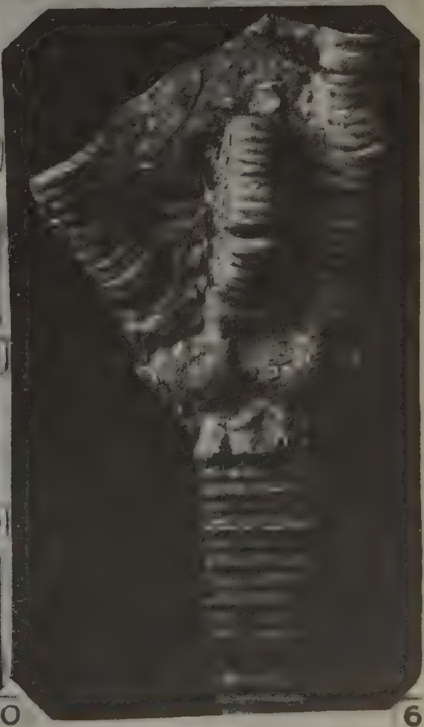
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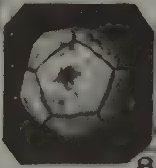
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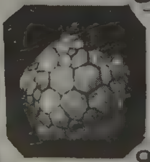
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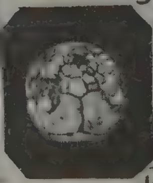
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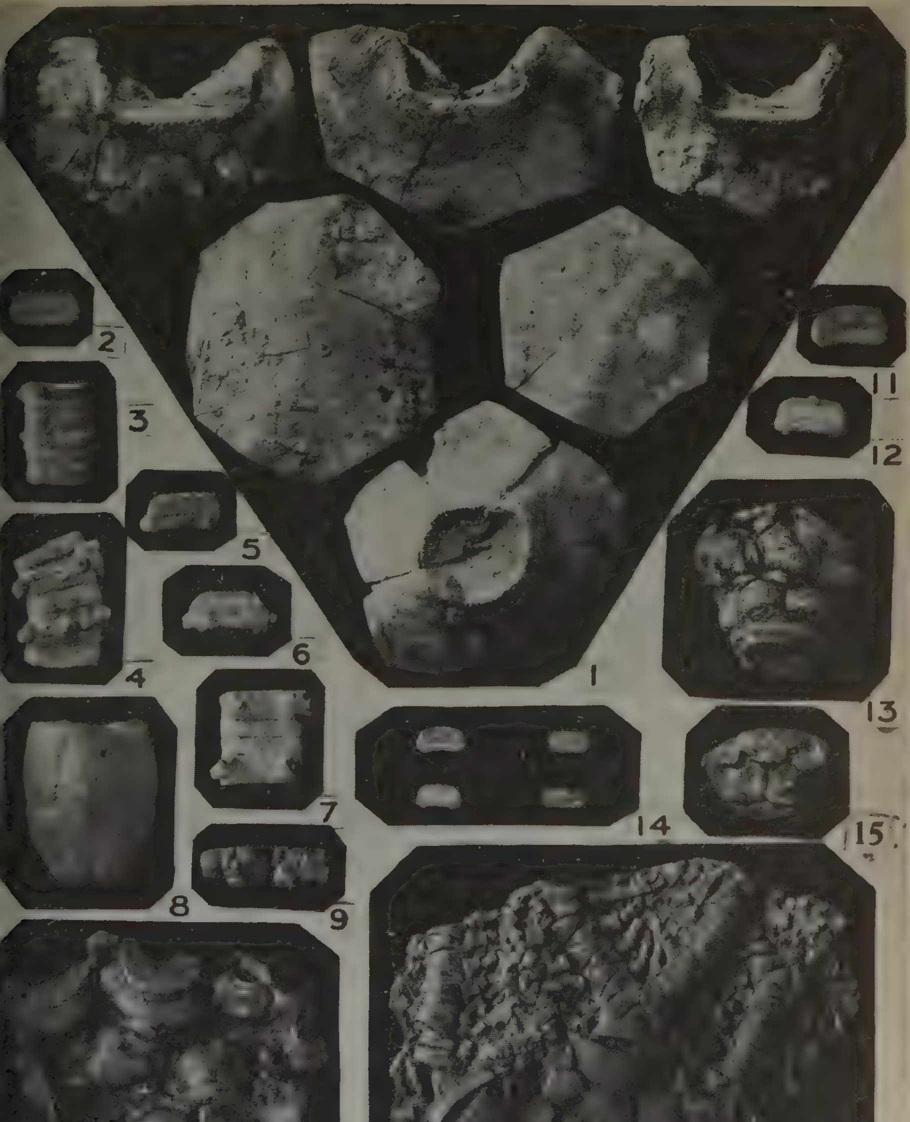
Photo J. Wright.

Scottish Crinoids.



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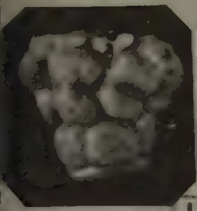
SCOTTISH CRINOIDS.



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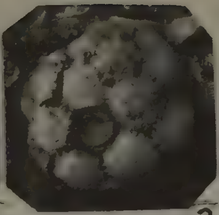

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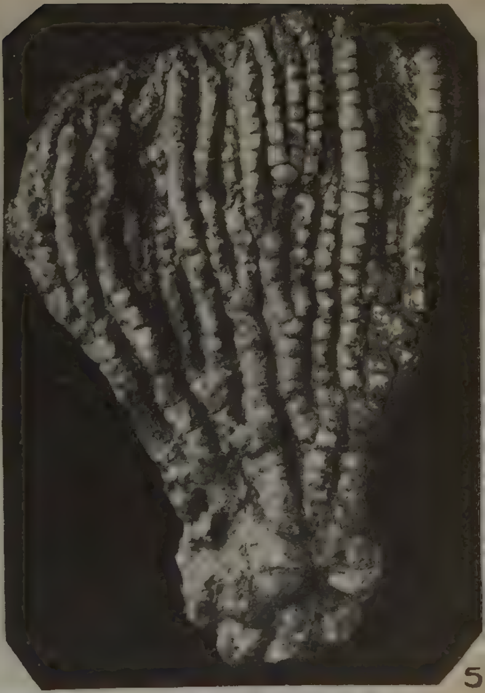

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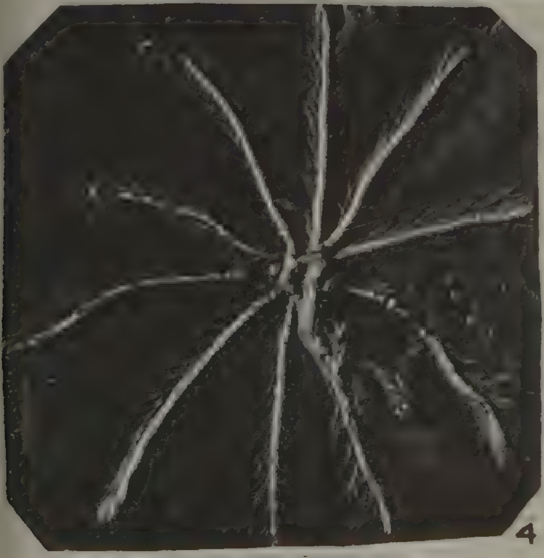

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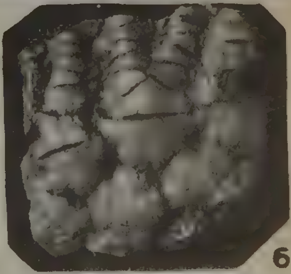

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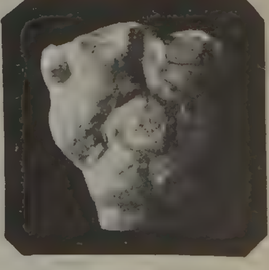

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Photo J. Wrigh

SCOTTISH CRINOIDS.

All from Lower Limestone Group, D_2, except species marked * which so far have only been found in the underlying Calciferous Sandstone Series, D_1. ** denotes species common to both divisions.

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ERRATA.—Wright, J., GEOL. MAG., 1936, LXXIII, 386, line 6: "**DICYCLICA ADUNATA** Bather" to read "**DICYCLICA INADUNATA** Bather".

V. EXPLANATION OF PLATES XIII–XVI.

PLATE XIII.

FIGS. 1–9.—*Rhodocrinus baccatus* sp. nov. Figs. 1, 2 and 3 nat. size; figs. 4–9 × 1½. Figs. 1 and 4, anterior views of holotype from No. 1 Bed, Invertiel. Fig. 9, anterior view of a specimen from Beith. Figs. 2 and 3, paratypes from No. 1 Bed, Invertiel. Fig.5, basal view of a paratype. Figs. 6 and 7, posterior and top views of the holotype. Fig. 8, a flattened specimen from Roscobie to show structure of plates.

FIGS. 10, 11 and 12.—*Poteriocrinus scotocarbonarius* sp. nov., from Roscobie, nat. size. Fig. 10, a slightly crushed specimen. Figs. 11 and 12, side and basal views of one of the paratypes, uncrushed.

FIGS. 13 and 14.—*Platycrinus conglobatus* sp. nov., from No. 1 Bed, Invertiel. Fig. 13, anterior view of holotype; Fig. 14, top view of a paratype, nat. size.

FIGS. 15 and 16.—*Platycrinus crassiconus* sp. nov., side and basal views of the holotype from No. 1 Bed, Invertiel. Fig. 15, × 1½, Fig. 16, nat. size.

FIG. 17.—*Platycrinus spiniger* sp. nov. from Roscobie, nat. size, the holotype showing basal circlet and one of the radials lying among scattered spiniferous columnals.

All author's collection except Fig. 9, which belongs to the Dunlop collection in Royal Scottish Museum.

PLATE XIV.

FIGS. 1–5.—*Poteriocrinus scotocarbonarius* sp. nov., from Roscobie, nat. size. Fig. 1, a large and much worn specimen showing contour of cup. Fig. 2, a flattened cup with a few columnals still adherent. Figs. 3 and 4, anterior and posterior views of another specimen. Fig. 5, side view of the holotype showing surface ornament, brachials, etc.

FIG. 6.—*Poteriocrinus pentonensis* sp. nov., from Penton Linns, the holotype, nat. size.

FIG. 7.—Fragment of stem of *Camptocrinus compressus* sp. nov. from Carlops. × 2.

FIGS. 8, 9 and 10.—*Platycrinus conglobatus* sp. nov., basal, top and side views of a small specimen from No. 1 Bed, Invertiel, nat. size.

All author's collection except Fig. 1, which belongs to the Bennie collection.

PLATE XV.

FIG. 1.—*Poteriocrinus magnus* sp. nov., from Roscobie, nat. size. Showing an infrabasal circlet, two detached basals and three radial plates.

FIGS. 2–9, 11, 12 and 14.—*Camptocrinus compressus* sp. nov., from Carlops, except Fig. 8, which is from No. 1 Bed, Invertiel. × 2. Figs. 2 and 11, detached non cirriferous columnals; Figs. 5, 6 and 12, cirriferous columnals; Figs. 3 and 4 two portions of stem showing outer surfaces; in both the cirriferous columnals are separated by two which bore no cirri and are smooth all round. Fig. 4 shows the cirri on two columnals crossing the outer surface from side to side. The fragment is slightly distorted and is smooth on the other side. Fig. 7, a portion of column from the inner surface, the reverse of Fig. 3. Fig. 8, a cup from posterior. Fig. 9, fragment of stem from the side. Fig. 14, columnals, nat. size.

FIGS. 10 and 13.—*Poteriocrinus scotocarbonarius* sp. nov., Fig. 10 from Roscobie, Fig. 13 from No. 1 Bed, Invertiel, both nat. size.

FIG. 15.—Small specimen of *Platycrinus crassiconus* from No. 1 Bed, Invertiel, with part of tegmen in position, slightly crushed, showing the contour of the calyx, nat. size.

FIG. 16.—*Pachylocrinus clavatus* sp. nov., from Roscobie, nat. size.

All author's collection.

PLATE XVI.

FIG. 1.—*Poteriocrinus scotocarbonarius* sp. nov., from Invertiel, Neilson collection, Royal Scottish Museum.

FIG. 7.—The same species from Clattering Well, Bishop Hill, somewhat worn.

FIG. 3.—Portion of stem very common at Roscobie and probably belonging to proximal region of the column of *Poteriocrinus scotocarbonarius*.

FIG. 4.—*Aesiocrinus* cf. *harii* Miller & Gurley, Penton Linns, Liddesdale.

FIGS. 2, 5 and 6.—*Pachylocrinus tyriensis* sp. nov. Fig. 5 from No. 3 Bed, Invertiel. Figs. 2 and 6 from Roscobie.

All nat. size, and all in author's collection except Fig. 1.

The Fishes of the "Crangopsis Bed" at Ardross, Fifeshire.

By ERROL IVOR WHITE.

Dept. of Geology, British Museum (Natural History).

FISHES in the *Crangopsis* bed in the Calciferous Sandstone at Ardross, Fifeshire, are rather rare and difficult to obtain, but now and then a few specimens come to hand. Since Traquair (1905, pp. 81–2) last summarized the fish-fauna of the Lower Carboniferous of Eastern Fife, Mr. James Wright and Mr. W. T. Kinnear have made small collections from Ardross, which comprise representatives of no less than six species additional to those recorded by Traquair, among them being well-preserved examples of two forms of which very few details were known, and of two new species.[1]

Most of the specimens are in counterpart, and are preserved in a fine-grained mudstone, of which the lime-content is sufficiently low to allow the use of acid to etch away the organic remains, thus leaving a fine, clear-cut mould of the fishes. In the case of specimens in counterpart, only the side showing the outer surface has been so prepared, for on the other nothing would be seen except the inner surface of the scales and bones.

With the exception of one counterpart, all the specimens here described are in the Department of Geology of the British Museum (Natural History), chiefly thanks to the generosity of Mr. James Wright and Mr. W. T. Kinnear.

[1] One of these, a Coelacanth, *Rhabdoderma ardrossensis*, is being described by Mr. J. A. Moy-Thomas.

Family **ACANTHODIDAE.**

Genus ACANTHODES Agassiz.

Acanthodes sulcatus Agassiz emend.

(Text-fig. 1.)

Acanthodes sulcatus, J. R. L. Agassiz, 1835, p. 125, pl. ic, figs. 1, 2.
Acanthodes sulcatus, R. H. Traquair, 1890, p. 392.

Diagnosis.—A species of *Acanthodes* of slender proportions, with maximum depth contained 5½ times in total length; pectoral fin-spine long, rather less than maximum depth in length; ventral spines about one-quarter as long and lying slightly nearer pectoral spines than anal, which is one-half as long; dorsal fin-spine somewhat shorter than anal and immediately behind it. All spines with single longitudinal groove close to and parallel with anterior border. Styliform bone of pectoral fin long and straight. Scales often with median depression and not flattened or overlapping those behind.

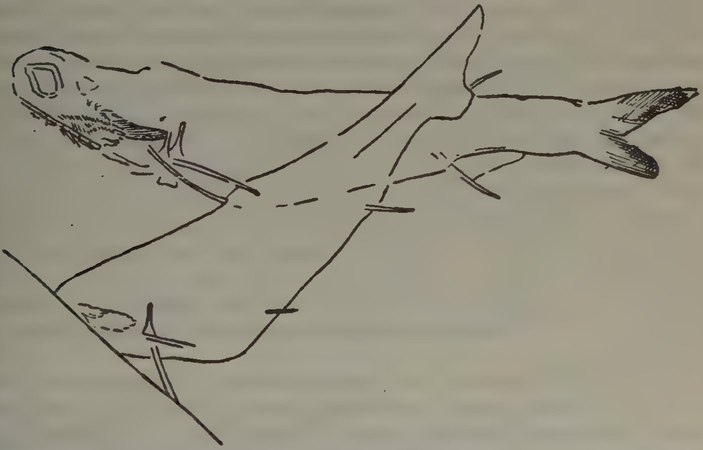
Material.—Two specimens on a single slab (Brit. Mus. (N.H.), No. P 11290, i, ii), R. H. Traquair Collection; the more complete specimen is here selected as the Neotype (i).

Description.—Of the two specimens one is complete, but it is overlain by the second, which is headless (Text-fig. 1). Like many other specimens of this family, they unfortunately show little beyond their form and proportions, the nature of the fin-spines and scales, and in one specimen the supports of the gill-covers. Their measurements are as follows:—

Specimen.	(i) *cm.*	(ii) *cm.*
Total length	11·0	—
Length to root of tail . . .	9·0	—
,, of head and branchial apparatus	2·8	—
Maximum depth	2·0	2·0
Depth of caudal peduncle . . .	0·8	0·8
Length of pectoral fin-spine . . .	1·7	—
,, ventral ,, . . .	—	0·5
,, anal ,, . . .	0·9	1·0
,, dorsal ,, . . .	0·7	—

The scales occasionally show the faint median depression which Agassiz (1835, p. 125) so much emphasized in his original description, but this is certainly not peculiar to the species and may not be even characteristic; however, in their lack of flattening and posterior overlap, especially in the region of the lateral line, they do seem to differ from those of a number of other Carboniferous species with which the form may be confused.

Remarks.—The status of this species has not been very satisfactory hitherto, for the character on which Agassiz originally based it, namely the median depression on the outer surface of the scales, is of no systematic importance, while his fragmentary type-specimen is specifically indeterminable. Later Traquair (loc. cit.) referred to *A. sulcatus* a number of more perfect specimens from approximately the same strata and area as the type, and in these he noted the length and straightness of the styliform bone as the sole characteristic. The Ardross specimens are similar in this respect, although generally somewhat more slender in form. Fortunately, the original specimen is apparently lost, and thus the species can be put on a firm basis by the selection of the complete Ardross specimen as the Neotype (P 11290, i). In general these specimens resemble most specimens of *A. wardi* Egerton and *A. nitidus* A. S. W., but the shape of the styliform bone and the nature of the scales seem sufficient to separate them.



Text-fig. 1.—*Acanthodes sulcatus* Agassiz. Sketch of two superimposed specimens, one lacking the head. The more complete specimen is the Neotype. (Brit. Mus. (N.H.), No. P 11290, i, ii. × ½ approx.)

Family **PALAEONISCIDAE**.

Genus ELONICHTHYS Giebel.

Elonichthys robisoni (Hibbert).

(Text-figs. 2–4.)

See R. H. Traquair, 1877–1914, p. 62.

Material.—A nearly complete fish in counterpart (Brit. Mus. (N.H.), No. P 19245, collected by Mr. James Wright; counterpart in Mr. Wright's Collection, No. 1999*b*.)

Description.—This specimen comprises almost the whole of the right side of the fish, the middle of the upper caudal lobe being the only part missing. The right-hand slab now shows a mould of the external surface, while the counterpart bears the inner bones of the skull and the squamation in mesial view.

The shape is typically fusiform, the head large with a blunt snout, the fins well developed, and the caudal peduncle deep and rather short.

The following are its measurements :—

	cm.
Total length	10–11
Length to base of caudal fin	7·0 approx.
,, of head and opercular apparatus	2·0 ,,
Maximum depth	2·4 ,,
Depth of caudal peduncle	1·1 ,,

Since Traquair (1877–1914, p. 62) has described this common species at some length, it will be necessary to mention only those points that are new. Unfortunately the details of the skull-roof and the inner bones of the skull are still unknown, for the former are obscured by the heavy external ornamentation, and the latter are too crushed to be decipherable. Parts of the cheek are, however, well preserved. The post-orbital is a large L-shaped bone which borders the orbit behind and partly below. The upper part is wide with a straight vertical orbital margin and a very convex posterior border fitting into the high, concave expansion of the maxilla (Text-fig. 2). The horizontal bar is narrow and more or less straight (the orbit being angular and not round), but its extent forwards is uncertain.

Within the orbit are two or three long, narrow "external sclerotics", which bear a strong ornamentation of elongated tubercles.

The ornamentation on the snout consists of numerous strongly developed tubercles that become elongated to form a well-marked "lane" above the sensory canals. The tubercular ornamentation is continued all over the skull-roof, the tubercles tending to fuse into short rugae towards the hinder end, while on the post-orbital they radiate from the orbit, but form vermiculating rugae on its expansion behind.

The anterior azygous branchiostegal ray is roughly diamond-shaped (Text-fig. 2) with the two anterior margins raised to fit into the angle of the lower jaw; it bears two short sensory canals arranged in a V near its centre. The first of the succeeding paired rays are nearly as broad as deep, and also bear a short sensory canal entering from the middle of the attached side. Thereafter follow half a dozen rather short and broad rays, but the remainder, except the two hindmost under the sub-operculum, are confused and ill-determined.

The ornamentation on the visceral bones consists entirely of ridges which are broken up into short lengths on the anterior bones, but are sparse and irregular on the wider surfaces. The sub-orbital bar of the maxilla, which is otherwise strongly ornamented, is smooth on the orbital side, where it was apparently overlapped by the post-orbital.

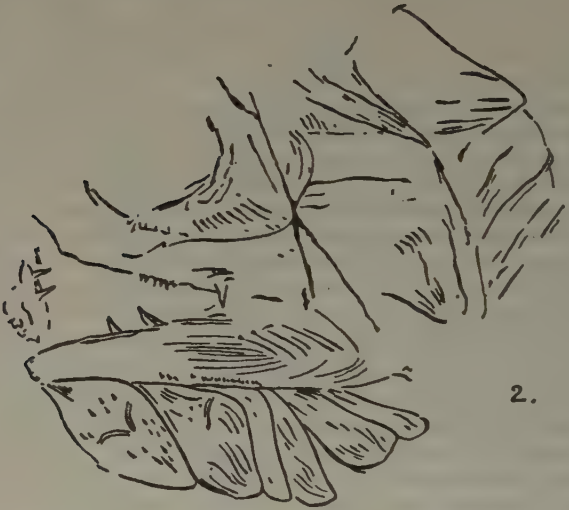
The teeth on the maxilla and mandible are similar. The outer teeth on both are numerous and pointed; all are small but they vary in size down to mere points which seem to grade into the tubercles of the ornamentation, while their arrangement is very irregular. The inner row of laniaries are conical and sharply pointed, their spacing being wide and fairly even.

The base of the dorsal fin, which is imperfect distally, is 1·7 cm. long. It starts a little in from the middle of the back, opposite the mid-point of the ventrals; at first there are ten or twelve graduated rays, of which the first is little more than a ridge-scale, and half a dozen following it increase very slowly in height. After about the twelfth ray there follow about twenty others, the height of which seems to decrease rather rapidly, so that the hinder margin of the fin is concave. The rays are stout and moderately distantly articulated, the middle and distal segments being 1½ times to twice as long as broad. Each is not only strongly fluted, but bears on its side a well-defined series of diagonal striae. The anterior margin of the fin bears numerous fine fulcra, about as long as the segments.

The anal fin, which is opposed to the hinder third of the dorsal, is very similar to that fin except that it has a shorter base, 1·3 cm. long, for there are fewer graduated rays in front, the eighth being approximately the longest. This ray is at least 1·8 cm. long, and is seen to dichotomize twice distally; behind it are about twenty graduated rays, which dichotomize three times and form a gently concave hinder margin at right-angles to the axis of the body.

Both the tail and the shoulder-girdle are as Traquair (1901, pl. x, fig. 1) has restored them, and so also are the pectoral fins, except for the nature of the anterior fulcra and the number of the rays. The latter is said by Traquair (1877–1914, p. 59) to be twelve, but at least double this number appears in our specimen and in other specimens, such as P 841 from Wallyford, in which the fin is well preserved.

In his description of *Elonichthys* "*striolatus*", Traquair (1877–1914, p. 59) describes the fulcra on the fins in general as being "closely set and minute", and thus figures them in his restoration of *E. robisoni* (loc. cit., pl. x, fig. 1); this is hardly true of any of the fins, while on the pectorals in our specimen (Text-fig. 3) they have the appearance of a complete ray minutely articulated by numerous transverse joints that are slightly concave upwards. Part of the more distal portion of the series from the left fin lie detached below the head (Text-fig. 4), and these show their method of attachment to the first fin-ray; the distal joints of the ray are very close and oblique, and the fulcra have the appearance of being extensions, two or more, from each segment. All specimens in which this part is well shown, such as No. P 9867 from Broxburn, Nos. P 11598–9 from Pumpherston, and one of the original specimens of "*E. affinis*" from Wallyford (Traquair, 1877–1914, pl. x, fig. 5), show this feature, and it seems that Traquair mistook



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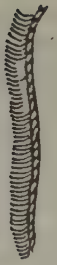

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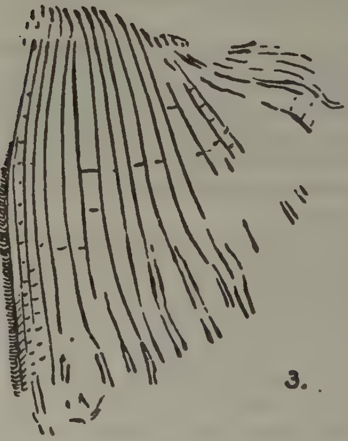


3.

Elonichthys robisoni (Hibbert).

Text-fig. 2.—Sketch of jaws, cheek, and opercular apparatus. (Brit. Mus. (N.H.), No. P 19245. × 3½.)
Text-fig. 3.—Right pectoral fin of same specimen. (× 6.)
Text-fig. 4.—Fulcra from the left pectoral fin of same specimen. (× 12.)

the obliquely and closely articulated segments of the first ray for the true fulcra. The origin of the ventral fins is midway between the pectoral pair and the anal, and is therefore farther to the rear than is shown in Traquair's restoration, but this is probably due to slight telescoping behind the dorsal fin. The base is 0·5 cm. long and there are thirteen or fourteen graduated rays, which bifurcate at least twice and resemble those of the unpaired fins in their ornamentation, while the fulcra are similarly long and fine.

The squamation is just as Traquair has figured and described it, and the ornamentation of the scales is of the "*robisoni*" type, with more or less diagonal rugae interspersed with pittings. This ornamentation is as usual stronger on the main flank-scales, which have six or eight posterior denticles, but it fades towards the tail. There are about forty-five vertical rows of scales, with about a dozen principal scales besides the shallow ventral scales in the more anterior rows.

Remarks.—This specimen was examined by Traquair years ago and pronounced by him to belong to a new species; but then the external sculpturing of the scales was not visible. As it is, the special features noted above in this specimen, the shape of the post-orbital, the number and fineness of the pectoral rays, and the size of the scales all seem to come within the wide range of variation of this exceedingly variable form, and, moreover, it is not possible to place this fish in any particular one of the several varieties described by Traquair (1877–1914, pp. 64–70), for it shows the characters of a number of these.

This is the commonest of all the Palaeoniscid fishes to be found in Lower Carboniferous strata of the Forth Basin, and it occurs in almost all the fish-bearing beds from the Wardie Shales to near the top of the Carboniferous Limestone Series; its presence at Ardross is therefore only to be expected.

Genus RHADINICHTHYS Traquair.

Rhadinichthys carinatus (Agassiz).

See R. H. Traquair, 1877–1914, p. 130.

Material.—An imperfect fish in partial counterpart (Brit. Mus. (N.H.), Nos. P 19246, P 20967; collected by Mr. James Wright).

Description.—This specimen had evidently reached an advanced state of decomposition before it was completely buried, for most of the bones of the head have disappeared save for a few opercular elements and the jaws in front and a post-rostral lying near the tail, while the squamation is much scattered and the ventral, anal, and dorsal fins have been destroyed.

There is nothing of special interest in this specimen, which corresponds closely with Traquair's (1877–1914, p. 130, pl. xxix, figs. 1–6) description of the species—the scales are smooth except for scattered punctures and the faint grooves which continue backwards the notches between the posterior denticulations; the post-rostral is long and narrow in front and expanded behind, with an ornamentation consisting of strongly marked tubercles in front, transverse ridges on its middle part, and faint longitudinal striae behind; the widely forked tail, which is almost complete, shows a well-marked epichordal lobe (cf. Watson, 1925, pl. ii).

Remarks.—This species is very widely distributed in the Calciferous Sandstone Series and the Edge Coal Series of the Midland Valley of Scotland.

Genus RHADINONISCUS nov.

(Etym. ῥαδινός, slender; ὀνίσκος, a sea-fish.)

Generic Diagnosis.—A Palaeoniscid of elongated form but with stout caudal peduncle; body-scales rhombic and strongly serrated behind, as are also upper dermal bones of shoulder-girdle and tabulars. Pectoral fin-rays distantly but completely articulated; dorsal fin remote, but origin anterior to that of anal. Suspensorium very oblique; branchiostegal rays very few, not exceeding four pairs. Only small marginal teeth known.

Genotype.—*R. wrighti* sp. nov.

Remarks.—At first sight the specimen on which this genus is based seems to be a fairly typical *Rhadinichthys* (see Traquair, 1877, p. 559; 1877–1914, p. 126) with its elongated form, remote dorsal fin, very oblique gape and so on, and indeed Traquair labelled it as such; but a more careful examination shows important differences in other characters—the branchiostegal rays, numerous in the type-species of *Rhadinichthys*, *R. ornatissimus* (Agassiz), and *R. carinatus* (Agassiz), are exceptionally few in our specimen, while the pectoral fin-rays, unarticulated till towards their terminations in the older genus, are segmented throughout; we may note in addition the deep caudal peduncle, which is not characteristic of species of *Rhadinichthys*.

The fewness of the branchiostegal rays is interesting: whether it is more than a generic idiosyncrasy is not clear. In the Middle Devonian *Stegotrachelus* (Woodward and White, 1926, p. 569) such a character was considered primitive, but in this instance it is certainly a result of specialization; it might conceivably be evidence of a trend towards the Catopterid line of evolution, for members of that group have no branchiostegal rays and commonly possess more or less smooth scales with strong posterior denticulations, not unlike those of *Rhadinoniscus* (Brough, 1931, p. 244).

Rhadinoniscus wrighti sp. nov.

(Text-figs. 5–10.)

Diagnosis.—As for genus (sole species).

Material.—The unique holotype, an imperfect fish, partly in counterpart (Brit. Mus. (N.H.), Nos. P 19247–8; collected by Mr. James Wright, in whose honour the species is named).

Description.—This specimen (Text-fig. 5) lacks the skull and the ventral fins; the following are its measurements:—

	cm.
Estimated total length	9·0
Length to root of tail	7·3
Estimated length of head and opercular apparatus	2·3
Maximum depth	1·5
Depth of caudal peduncle	0·6

The tabular row, the sole remains of the skull-roof, consists of at least two pairs of four-sided bones, of which both are broader than long and strongly denticulated behind, and the outer pair are larger than the inner: there was possibly yet another pair, or an azygous element (Text-fig. 6, *Tab.*). Three post-orbitals are to be seen (*P.O.*), of which the largest is roughly triangular and borders the hinder part of the orbit in front and the maxillary expansion below, while between its posterior upper margin and the slightly excavated anterior face of the large triangular preopercular expansion are two other post-orbitals, more or less quadrate in shape. The lower margin of the orbit is formed by a long, narrow bone (*Ju.*), which receives the sub-orbital sensory canal, preserved as a calcite cast (*S.O.C.*), from the anterior post-orbital, in which a short branch may be seen running to the surface of the bone near the lower border.

The suspensorium may be traced on the right-hand slab, lying at an angle of about 45°.

The maxilla is of the usual Palaeoniscid pattern, but the posterior expansion is very long and passes forwards gradually into the sub-orbital bar, while the posterior downward inflection of the lower margin over the mandible is unusually large.

The lower jaw is stout and long.

Little can be seen of the dentition on either jaw except sockets and partial impressions of minute marginal teeth.

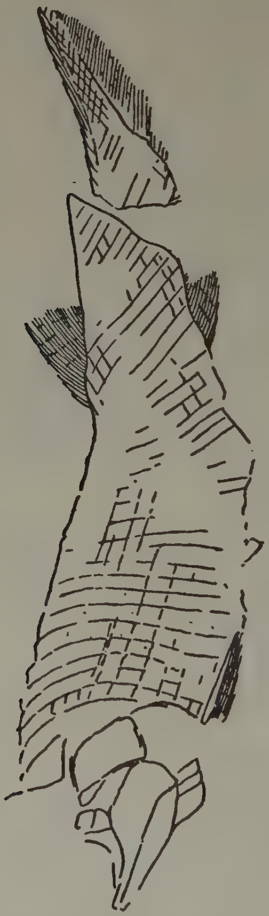
The oblique operculum is about half as high again as it is broad at the base; the front and lower margins are nearly straight and at right angles to one another, while the hinder and upper margins form an almost continuous curve. A large triangular ant-operculum lies between its upper front margin and the pre-operculum.

The sub-operculum is very large, and owing to the obliquity of the operculum, the convex hinder margin is twice as long as the concave anterior border, and is slightly greater than the maximum breadth.

Only four branchiostegal rays can be seen: that immediately under the sub-operculum is, as usual, deep, and is succeeded below by two narrow and short rays at the angle of the lower jaw, in front of which is a large, almost symmetrically diamond-shaped element, the form of which clearly stamps it as the first paired ray. The series was probably completed by an anterior azygous ray, but this is not preserved.

The post-temporal is large and triangular, and the supra-cleithrum high and fairly broad, with its upper end extended forwards to separate the outer tabular and the operculum. The hinder margins of both the post-temporal and the supra-cleithrum are strongly denticulated.

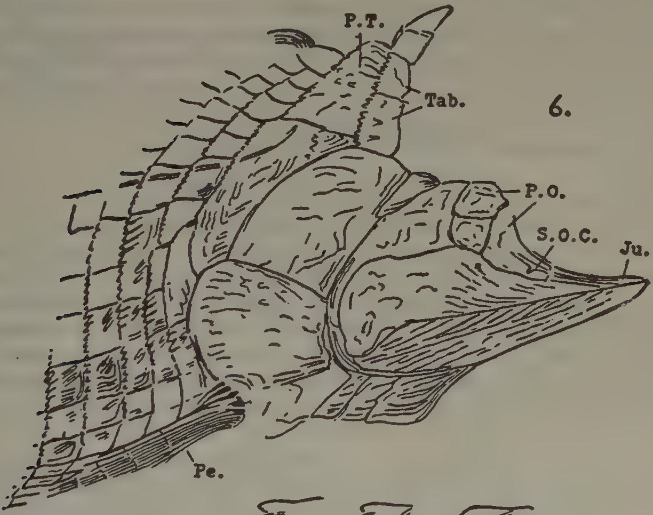
Below and somewhat behind the supra-cleithrum is a large post-cleithral scale, but of the cleithrum nothing can be seen except a few fragments in front of the pectoral fin.



TEXT-FIG. 5.—*Rhadinoniscus wrighti* gen. et sp. nov. The holotype (Brit. Mus. (N.H.), No. P 19247, × 1⅔.)

The ornamentation on most of the bones described above consists of flattened, vermiculating rugae, except on the lower jaw and supra-cleithrum, where there is the usual tendency to form a herring-bone pattern, while on the otherwise smooth outer tabulars a row of large raised denticles runs across the breadth of the bone.

The pectoral fins lie folded along the ventral margin of the body. Nine or ten rays may be counted on one side, of which the anterior (and largest) measures 0·9 cm.; it is, however, doubtless incomplete. Each ray is very distantly articulated throughout, only five articulations being visible in the part preserved, and no fulcra are to be seen.



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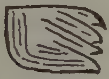

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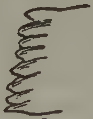

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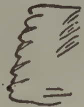

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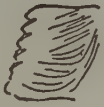


7.

Rhadinoniscus wrighti gen. et sp. nov.

TEXT-FIG. 6.—Anterior region of counterpart of holotype. *Ju.*, jugal; *Pe.*, pectoral fin; *P.O.*, post-orbitals; *P.T.*, post-temporal; *S.O.C.*, sub-orbital sensory canal; *Tab.*, tabulars. (Brit. Mus. (N.H.), No. P 19248 × 3⅜.)

TEXT-FIGS. 7–9.—Flank-scales of same specimen. (× 7.)

TEXT-FIG. 10.—Posterior scale of holotype. (× 7.)

Of the ventrals there is no trace.

The dorsal fin lies rather far back, above the twenty-seventh scale-row. It comprises about twenty-three rays on a base of 0·7 cm. The rays are distantly jointed throughout, but they are defective distally, so that no dichotomy can be seen. An ornamentation of fine, slightly diagonal ridges is to be observed on the sides of the rays. The fin is steep in front, the first seven or eight rays being successively longer, but the outline of the hinder border cannot be determined with accuracy.

The anal fin, which starts opposite the middle of the dorsal base, is similar but a little smaller, there being evidence of about twenty rays. It is very much more defective than the dorsal fin, but its anterior fulcra are better shown, large and few, alternating with the tips of the graduated rays.

The tail is very defective, for the whole of the lower lobe and the extremities of the upper rays are missing, as is also the tip of the body prolongation. The missing part of the latter was probably quite short, to judge by the fineness and length of the upper caudal fulcra preserved, so that the tail was short and strong. The rays are very fine and numerous, and much more closely articulated than in the other fins.

The squamation is disposed in about thirty-eight rows to the base of the tail, and anteriorly there are nineteen or twenty scales in each row, the principal flank-scales being considerably taller than broad (Text-figs. 7–9), but the series decreases in height, as is usual, dorsally, posteriorly (Text-fig. 10), but especially ventrally, where there are half a dozen rows of very shallow scales. Along the middle of the back there seem to be an azygous row of oval scales scarcely larger than their neighbours. There are the usual small lozenge-shaped scales on the caudal body-prolongation and elongated fulcra along its upper margin.

The scales are all strongly serrated behind, the principal flank-scales bearing from nine to eleven denticles, which are slightly raised, the ridges continuing forwards and slightly upwards on to the surface of the scale. In addition there is a number of faint ridges running firstly parallel with the anterior margin and then with the lower, as well as a series of delicate grooves, often obliterated, which run obliquely downwards from the upper anterior corner. The whole of the ornamentation becomes fainter and tends to disappear as the scales become shallower. The lozenge-shaped scales on the tail bear fine longitudinal ridges.

On the inner surface of the scales there is a strong vertical rib, and doubtless also the usual peg-and-socket articulation.

Remarks.—See under genus.

Genus CANOBIUS Traquair.

Cf. **Canobius politus** Traquair.

See R. H. Traquair, 1877–1914, p. 178.

Material.—External mould of the right side of the trunk of a fish (Brit. Mus. (N.H.), No. 19249 ; collected by Mr. James Wright).

Description.—This specimen consists of the trunk of a moderately deep-bodied fish without either head or tail, and with only fragments of the fins. Its most striking feature is that the external surface of the scales is without any form of ornamentation save for a few obscure diagonal grooves running forwards from the coarse posterior denticulations. This fragment is 4·7 cm. long, with a maximum depth of 2·4 cm.

Remarks.—This specimen most resembles in the character of its squamation those described and figured by Traquair (1877–1914, p. 179, pl. xxxix, figs. 12–16) as *Canobius politus*, but it is rather stouter in its proportions: its reference to this species, or even to this genus, for it shows no generic characters of any importance, must be purely tentative. I have to thank Mr. J. A. Moy-Thomas, who is revising the genus *Canobius*, for his opinion on this identification.

Family **PLATYSOMIDAE**.

Genus CHEIRODUS M'Coy.

Cheirodus crassus Traquair.

(Text-figs. 11–17.)

Cheirodus crassus R. H. Traquair, 1890, p. 400.

Diagnosis.—A species of *Cheirodus* resembling *C. granulosus* except in minor details of head bones, and in ornamentation of flank-scales: the latter is coarsely granular with the granules frequently fusing to form horizontal ridges on posterior half of scale.

Lectotype.—Isolated flank-scale. [Royal Scottish Museum, No. 1905.10.56; text-fig. 17.]

Material.—One almost complete but naturally damaged specimen, in counterpart (Brit. Mus. (N.H.), Nos. P 16160, P 20441; collected by Mr. W. T. Kinnear); also seven isolated scales from Abden, the co-types, six in the Royal Scottish Museum, and No. P. 11730 in the British Museum (N.H.).

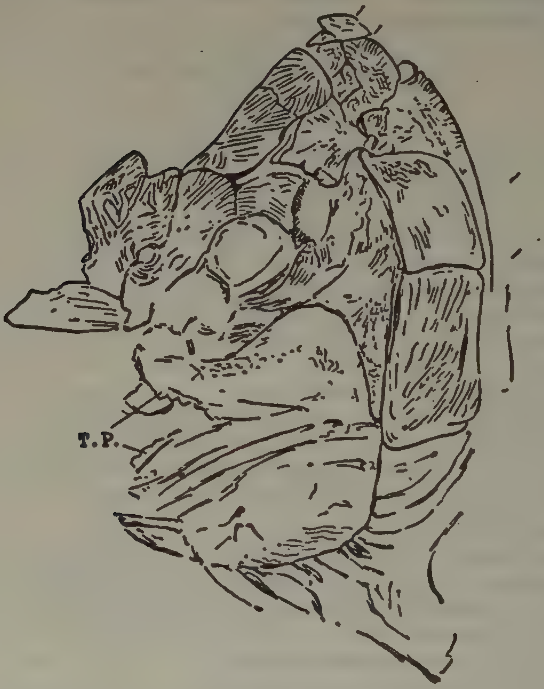
Description.—This specimen is nearly complete, but has suffered decomposition before burial: a large piece is missing from the back in front of the dorsal fin, the pre-orbital region of the face is scattered, while all the fins are defective and the caudal region telescoped. The following are its measurements:—

	cm.
Estimated length to the root of the tail . .	14–15
,, maximum depth	14–15
,, length of the head and opercular apparatus	4·5
Depth at the occiput	6·0

It was roughly of the same rhombic form as *C. granulosus* (Young) and had similar proportions, perhaps a little deeper (see Traquair, 1880, pl. v, fig. 1).

The parietals (Text-figs. 11, 12, *Par.*) are quadrate, a little shorter than broad; their suture with the frontals is hardly discernible, suggesting that they were partly fused together. The frontals are twice as long as wide along their outer margins and three times along their inner borders, where they are produced forwards to fit into the posterior emargination of the equally long post-rostral (*P.R.*). The latter widens gradually from behind forwards to about the middle of its length, where there is a rounded excavation for the nostril, in front of which it is narrow. Anterior to the post-rostral are the long paired, beaklike elements, usually determined as premaxillae. Behind the parietals are some bones, which may be small tabulars or just nuchal scales.

Below the parietal and the posterior part of the frontal is the large trapezoidal supra-temporal, and again below this a wide inter-temporal (*I.T.*), forming the upper margin of the orbit, which is completed by a tall, narrow post-orbital behind, a very large more or less triangular lachrymal in front and below, and a long, irregularly shaped nasal in front and above.

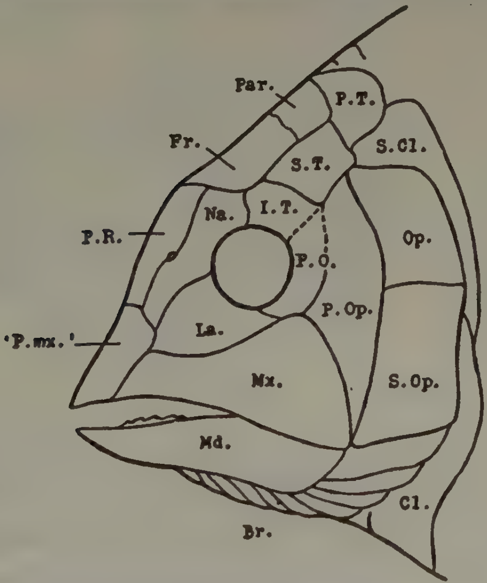


Text-fig. 11.—*Cheirodus crassus* Traquair. Squeeze of head and opercular apparatus taken from left-hand slab. *T.P.*, tooth-plates. (Brit. Mus. (N.H.), No. P 20441. × 1⅓.)

The jaws and opercular apparatus are very similar to those in Traquair's (1880, pl. v, fig. 1) well-known restoration of *C. granulosus*, and offer no points of special interest. Only fragments of the tooth-plates are preserved, but these show a few broad, blunt denticles (*T.P.*).

The post-temporal (*P.T.*) is a large trapezoidal bone, while the supra-cleithrum below has a large head projecting forwards as far as the supra-temporal. The cleithrum is, as usual, expanded in front of the pectoral fin.

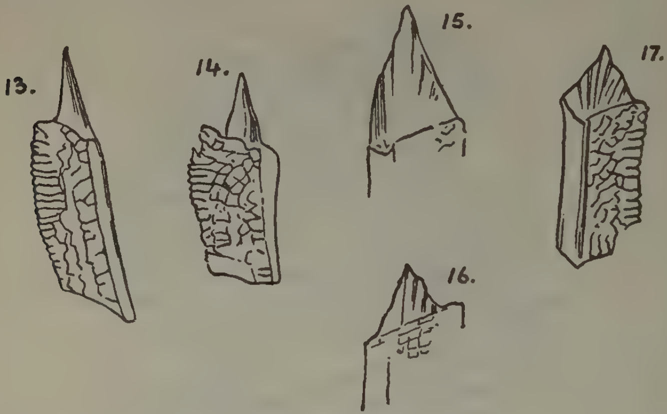
The ornamentation on the head consists chiefly of moderately fine, flat rugae, which run roughly parallel with the length of the long bones, or radiate from centres of ossification (Text-fig. 11).



TEXT-FIG. 12.—*Cheirodus crassus* Traquair. Restoration of head and pectoral girdle. *Br.*, Branchiostegal rays; *Cl.*, cleithrum; *Fr.*, frontal; *I.T.*, inter-temporal; *La.*, lachrymal; *Md.*, mandible; *Mx.*, maxilla; *Na.*, nasal; *Op.*, operculum; *Par.*, parietal; "*P.mx.*," "premaxilla"; *P.O.*, post-orbital; *P.op.*, pre-operculum; *P.R.*, post-rostral; *P.T.*, post-temporal; *S.Cl.*, Supra-cleithrum; *S.Op.*, sub-operculum; *S.T.*, supra-temporal. (× 1¼.)

On the opercular bones the ridges tend to become broken up, but not to the same extent as they do in some specimens of *C. granulosus*.

The squamation as a whole is poorly preserved, but there is sufficient to show that in number of rows, form, and distribution of the scales it resembled *C. granulosus* as drawn in Traquair's well-known restoration (1880, pl. v, fig. 1). In his scanty diagnosis of *C. crassus*, Traquair (1890, p. 400) noted that the scales had "a relatively coarser ornament than in *C. granulosus* Young; and the internal rib or 'lepidopleuron', not nearly so distinctly marked off . . .". The internal rib does seem less strongly developed than in most specimens of that species, and the ornamentation is coarser (Text-figs. 13–17); the latter has a very characteristic arrangement on the flank-scales which readily distinguishes them from those of other species—on the anterior half of the scales the rugae are broken up into flat tubercles; very irregularly arranged on the whole but with a tendency to vertical alignment, while on the posterior half they are more complete and run horizontally, forming blunt denticles along the hinder margin. This is shown very well on one of the original specimens, which I have selected as lectotype (Text-fig. 17), and to a less extent on another, P 11730, a very large scale which indicates a fish twice as large as the Ardross specimen.



Cheirodus crassus Traquair.

Text-figs. 13–14.—Flank-scales from an external mould of a nearly complete specimen. (Brit. Mus. (N.H.), No. P 20441. × 3 approx.)

Text-figs. 15–16.—Upper part of flank-scales from the counterpart of the above. (Brit. Mus. (N.H.), No. P 16160. × 3 approx.)

Text-fig. 17.—One of Traquair's original specimens, an isolated flank-scale. The lectotype. (Royal Scottish Museum, No. 1905.10.56. × 3 approx.)

Of the fins the anal is alone moderately complete; it is long and fringe-like, except for the peak in front, immediately in front of the ventral angle of the body. The rays are numerous, closely set and articulated, while fulcra appear along the graduated anterior margin.

The tail has been much disturbed, but it was obviously widely forked and nearly equilobate. A series of large fulcra occur along the dorsal margin and a finer series strengthens the lower anterior border.

Remarks.—This species was first noted by Traquair (1890, p. 400), who gave a very brief and inadequate diagnosis based on a few isolated scales from Abden. He emphasized only the relative coarseness of the ornamentation and the less obvious inner rib, as compared with similar features on the scales of *C. granulosus.* Fortunately the original specimens are available for comparison with the new specimen, thanks largely to the courtesy of Dr. A. C. Stephen, the Keeper of the Natural History Departments of the Royal Scottish Museum, and it is clear that they are of the same species, and that this species is readily distinguishable from the two Upper Carboniferous forms. The genotype, *C. pes-ranae* M'Coy, is based on an isolated splenial bone, and with this no comparison is possible.

SUMMARY.

One of the first authors to note the Ardross fauna was the Rev. T. Brown (1861, pp. 394–5), who " detected small scales of some species of Palaeoniscus, and a good specimen of an Amblypterus, which seemed to be the *A. striatus*. There were teeth and scales also of a Holoptychius ; and their resemblance to the figure of the *H. portlocki* . . . seemed to be complete ".

The fauna was summarized by Peach (1902, pp. 357–375), who, in addition to two plants, four arthropods, five brachiopods, and six lamellibranchs, gave the following list of fishes :—

Oracanthus armigerus Traquair.
Euphyacanthus semistriatus Traquair.
Acanthodes sulcatus Agassiz.
Coelacanthopsis curta Traquair.
Elonichthys pectinatus Traquair.
Eucentrurus paradoxus Traquair.[1]
Helodont tooth.

Some of the species listed above were not described, however, until some years later (Traquair, 1905).

Peach described the fauna as coming from his locality 50, i.e. " Shore east of Ardross Castle—shale underlying bands and nodules of limestone ".

To this list we must now add the following species described above :—

Elonichthys robisoni (Hibbert),
Rhadinichthys carinatus (Agassiz),
Rhadinoniscus wrighti gen. et sp. nov.,
Cf. *Canobius politus* Traquair,
Cheirodus crassus Traquair,

while, in addition, Mr. Moy-Thomas is describing a new species of Coelacanth (in the press) :—

Rhabdoderma ardrossensis sp. nov.

If we omit Brown's rather doubtful identifications, there are at least twelve, possibly thirteen, species of fishes, two plants, and, with the addition of *Aganaster gregarius*, an American ophiuroid recorded by Spencer (1925, p. 285), sixteen invertebrates. The size of the fauna in respect of the number of species is quite remarkable, for although some of the invertebrates, such as the Arthropod, *Crangopsis* [*Palaeocrangon*] *socialis*, which gives the bed its name, have been found in fair numbers, most of the species of fishes are represented by single specimens, so that the length of the faunal list is a tribute to careful and painstaking collecting.

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[1] Moy-Thomas (1937) has recently pointed out the Bradyodont affinities of this curious fish.

In conclusion I wish to express my thanks to Mr. James Wright and Mr. W. T. Kinnear for the opportunity of describing their specimens and for information concerning the bed, to Mr. J. A. Moy-Thomas for showing me the material that he is describing, and to Dr. A. C. Stephen for the loan of specimens from the Royal Scottish Museum, Edinburgh.

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REVIEWS.

THE PRINCIPLES OF DISTRIBUTION OF CHEMICAL ELEMENTS IN MINERALS AND ROCKS. By V. M. GOLDSCHMIDT. *Journ. Chemical Soc.* 1937, pp. 655–673.

THE contents of journals published in this country are not usually reviewed in these pages, but it seems useful to draw the attention of petrologists and mineralogists to an important publication which they might perhaps otherwise miss. In this, the seventh

Hugo Müller lecture delivered before the Chemical Society on 17th March last, Professor Goldschmidt gives a summary of the work of himself and his colleagues, of late mainly at Göttingen, on the distribution of elements in the earth's crust, with a useful bibliography for the last seven years.

THE MINERAL RESOURCES OF THE UNION OF SOUTH AFRICA.

pp. 454. With numerous maps, figures, tables, and diagrams. Pretoria: Department of Mines. 1936. Price 1*s*.

THE contents of this remarkably cheap publication are so varied that it is impossible even to enumerate them. We may, perhaps say, comprehensively, that it contains all the information there is on its extremely wide subject, and is beautifully illustrated, including two coloured maps, physiographical and geological respectively. It is essentially a new edition of a work prepared by the late Drs. Wagner and Reinecke for the International Congress in 1930, and now issued under the editorship of the Director of the Geological Survey of the Union. The government is much to be congratulated on its enterprise in bringing out this most useful work.

IST DIE ANNAHME VON EISZEITEN BERECHTIGT? By C. G. S. SANDBERG.

pp. 56 with 8 figures. Leiden: Sijthoff. 1937.

NINE years ago in a paper published in this Magazine Dr. Sandberg revived the long-abandoned theory of the volcanic origin of the Dwyka Conglomerate of South Africa, basing his arguments mainly on the resemblance between this deposit and certain phenomena, admittedly of volcanic origin, in the Netherlands East Indies. In the publication now under review Dr. Sandberg amplifies his former objections to a glacial interpretation of this and similar deposits by denying *in toto* the glacial origin of the drifts of northern Europe and of North America, although these last are not discussed in detail. To deal adequately with the arguments set forth would require at least a whole number of the Magazine, but it may be noted that Dr. Sandberg even appears to question the identification of Scandinavian rocks in the boulder-clays of Britain, as he certainly does in some German instances. He might gain some illumination from a study of the boulder-clays of the east of England. The alternative explanation, darkly hinted at as forthcoming in a future publication, will be awaited with much interest. It may be recollected that the late Sir Henry Howorth, in a somewhat similar campaign, conjured up a demon much worse than the one that he set out to exorcise.

CORRESPONDENCE.

GEOLOGY OF KAVIRONDO.

SIR,—Speaking for my colleagues and myself, we are well content to leave geologists who know the Kavirondo goldfield and its history to decide for themselves whether the implications contained in Dr. Pulfrey's letter (GEOLOGICAL MAGAZINE, February, 1937) are deserved or not; but it may be pointed out that the term "Kakamega area" as understood in Kenya now is a subdivision of convenience; it had no existence when Combe was working in Kavirondo and has no geological meaning to-day. Dr. Pulfrey's statement that "Mr. Combe's reports deal with an area south-west of the Yala" is inadequate; the area was south, west, north, and round to the east of the Yala thus including some of the "Kakamega area" as at present defined, to which Dr. Pulfrey seems to consider it has no reference, despite the fact that the *raison d'être* of its investigation was to open the path for the search for gold.

Admittedly the discovery that heralded the opening up of the Kakamega goldfield was made by non-officials, as I have more than once stressed in print[1]; and it is not a "controvertible point" that Combe's report led the pioneers to make that discovery. They had nothing to gain by proffering that information except the ordinary satisfaction of stating the full truth, which they hastened to do, gratefully, it seems, in the Press. That announcement was the first news we had of the discovery of gold in Kakamega.

It frequently happens in a new goldfield that quite a number of people find they knew the gold was there "all along". Perhaps this is true of Kavirondo? But it seems significant that the late Professor J. W. Gregory, who was our most up-to-date authority when Combe investigated and reported on the area in question, could write of the Kakamega area in his *Rift Valleys and Geology of East Africa* without mentioning gold, in spite of the fact that he had an important chapter on Mineral Resources, in which all he had to tell of the occurrences of the precious metal in the Colony was that: "Gold is said to occur in the Lol Daika hills and has been recorded from Jombo" (p. 255), and "the information available does not encourage much hope that the country will be found rich in the more valuable and high-priced minerals" (p. 250).

Dr. Pulfrey states that it was the rise of the price of gold that first turned people's thoughts to the winning of it in Kenya. That is not so. It was the slump in other commodities that brought distress to the Kenya farmers, who were glad enough to turn their hands to anything likely to bring grist to the mill, and the discovery in Kavirondo naturally attracted them. At that time the price of gold was 84*s*. 9*d*.–84*s*. 11*d*. It began its spectacular rise after the discovery, but had it been only half the figure mentioned the farmer would still have sought it.

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[1] "Beginnings of Kakamega," *East Africa*, 30th May, 1935, pp. 827–8.

Nor is Dr. Pulfrey in happier case when he refers to the "private report". So little private indeed was that document that it was especially written for publication, together with a map. But when all was ready we learnt that Sir Albert Kitson was coming out to Kenya, and as we did not wish to appear to rush in under the nose of the consultant, the report was withheld from the printer but its contents were made available to those interested. Actually, the main facts of that report had already appeared in the Annual Reports of this office previously referred to (GEOLOGICAL MAGAZINE, July, 1936, p. 331). To my certain knowledge the so-called private report was made use of by Sir Albert Kitson, and several other geologists.[1] It was in no way confidential.

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THE BALLARD DOWN FAULT.

SIR,—May I appeal to Mr. Brydone to give me the credit for a genuine desire to discover the truth, and not to "score off" him, to "blunt his points", or to strike an "attitude"? If I have poached on his preserves in Dorset it was done in innocent unawareness that he was working on tectonics.

I cannot leave his first paragraph uncorrected. I "asserted" nothing new in 1936, with regard to the relative ages of the chalk above and below the Ballard Down Fault that had not already been asserted by Strahan in 1898, and I modified Strahan's assertion by calling attention to the subsequent work of Rowe. After sifting Strahan's statements, and still clearly referring to them, my words were: "The actual observations or facts that we are justified in setting down . . . appear to me to be limited to the following" (GEOL. MAG., 1936, 59). It seems that this could hardly be called an assertion (still less a new one) by anyone who did not desire to misrepresent my views. Those views, for what they are worth, are stated in GEOL. MAG., 1937, 86.

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STRENGTH OF THE EARTH'S CRUST.

SIR,—A paper recently read before the Geological Society of London dealt with marine platforms which occur in Cornwall, Wales, and Scotland at heights above present sea-level up to 1,000 feet; and in the discussion the question of the whole country rising as a unit was mentioned. Even if it is eventually established that there are platforms of marine origin over a wide area at concordant heights, it should be realized that a very large block of crust could not act like this by reason of sufficient strength of its own.

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[1] Murray-Hughes, R., "Notes on the Geological Succession, Tectonics and Economic Geology of the Western Half of Kenya Colony," *Report No. 3, Mining and Geological Dept., Kenya Colony*, 1933.

Some imagine that such a block of crust could behave in a manner similar to a floating raft, in that if one pushed down a corner, the opposite corner will rise ; but there is an evident example of weakness in Scandinavia. Everyone who has studied the evidence of former sea-levels here, from Sederholm onwards, is agreed that the crust is recovering from isostatic depression, and a rough estimate of the force that is restoring the *status quo* can be made. It is only necessary to assume a figure for the amount of recovery still to be effected ; some are of opinion that the fjords have already recovered —though the floor of the Gulf of Bothnia is still rising—but if we assume, in order to get an outside estimate, that they have not recovered and that the deeper inner parts were not entirely carved out by glacial overdeepening in the confined space, then taking Hardanger Fjord as 980 feet deep and Sogne as 2,800, an estimate of 2,000 feet for further recovery at the middle of the depression is not unreasonable.

Taking the country affected as 500 miles across, the slope from each side towards the middle averages only about 1 in 600. The force tending to restore this to the horizontal must be very small.

If we assume that 2,000 feet of crust of specific gravity 2 is depressed into supporting magma of specific gravity 3, the upthrust is equal to the difference, that is 2,000 feet of specific gravity 1. A column of water one inch square and 2,000 feet high weighs approximately 870 pounds, so that on these figures the force tending to restore equilibrium is less than half a ton per square inch at the middle, and of course still less towards the periphery.

Those familiar with the region would probably say that 2,000 feet is a gross overestimate, but might concede half this ; which gives a figure of much less than a quarter of a ton per square inch. Yet the massive crust is responding to such a feeble force in a supine manner, the Palaeozoic floor equally with the heavily-injected strata folded on to its edge.

It would seem that the crust here (and this is a fair sample of the whole) yields to a feeble but long-imposed force in a manner which answers—up to a point—to the definition of viscosity ; so that, if a block of crust shows a marine platform equidistant from sea-level throughout its length, we may take it that the block is being supported equally at every point.

The same figures tell us that, conversely, if for any reason the serenity of the supporting magma should be disturbed, the crust—unable to support its own weight for long—would reproduce at the surface every disturbance. We may yet have to think of it as a very flexible raft riding on a not-too-quiet sea.

R. G. Lewis.

Hillthorpe,
Loughton, Essex.
19th April, 1937.

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ORIGINAL ARTICLES.

The Relationship of the Pilton Beds of North Devon to their Equivalents on the Continent.

By Henry Paul (Essen).

HAVING made a general study of the Devonian-Carboniferous junction in North-West Europe and a more detailed one of special areas, the author discusses here the correlation of the Pilton Beds of North Devonshire and the " K beds " of the Bristol and Forest of Dean areas with the Etroeungtian and other horizons near the Devonian-Carboniferous boundary on the Continent.

The Pilton Beds.

The Pilton Beds of North Devonshire are of considerable thickness. Although folding and faulting renders it difficult to reach any true estimate of their actual thickness, the author considers this to be somewhere near 5,000 feet. They consist of bluish-grey sandy micaceous slates, calcareous shales (found mainly in the higher part) and calcareous sandstones. Impure crinoidal limestones are also found, but only as occasional lenticles. Thick beds of limestones built up of crinoid stems, rugose corals, and stromatoporoids, so characteristic of the Continental equivalent, are absent. Fossils are very often distorted by cleavage and casts, in a good state of preservation, are only found in decalcified sandstones.

The Pilton Beds are underlain by the Marwood, Baggy, or *Cucullaea* beds, which are considered to be for the *most part* of freshwater to shallow sea-water origin. These beds must have been deposited very near the shore line of the old Tethys.

On the other hand the Pilton Beds pass gradually upwards into the Lower Culm—the Coddon Hill Beds, which are well exposed in different places north of Fremington. These consist of horizontal decalcified shales with numerous badly preserved fossils and occasional phosphatic nodules[1] followed by unfossiliferous slates containing nodules of pyrite. The slates are, in their turn, overlain by soft yellow shales with fossils[2] and abundant phosphatic nodules. Both the dark slates and the shales with phosphates are considered to be the lowest part of the Culm.

The uppermost part of the Pilton Beds near Fremington have yielded among other fossils an early mutation of *Linoproductus corrugatus* (M'Coy),[3] only known on the Continent from beds *overlying* the Etroeungt beds. *Phillipsia hicksi* has also been recorded from Fremington.[4] *Phillipsia*, which has never been found in the Etroeungt Beds, is first found in the Hastière Limestone that immediately succeeds the Etroeungt limestones and shales. From this it may be concluded that the uppermost part of the Pilton Beds (those exposed on the shore at Fremington) include the Hastière Limestone of Belgium.

The fauna of the Pilton Beds has both a Devonian and a Carboniferous aspect and therefore the horizon ought to be considered lowest Carboniferous. It is rich in species, but the specimens are not well preserved.

Simple rugose corals, such as *Palaeosmilia aquisgranensis*, *Caninia dorlodoti*, and *Clisiophyllum omaliusi*, so characteristic of the same horizon in Northern France, Belgium, and North-Western Germany, are entirely absent; so are Stromatoporoids, which are abundant in places on the Continent. These are very abundant in North France, at Aachen, and in the higher part of the Etroeungtian at Ratingen, but are extremely rare in Belgium, where they have only been found on the River Ourthe.

Michelinia, another characteristic genus on the Continent, is not represented in the Pilton Beds.

Pleurodictyum sp. is represented in the Barnstaple Athenaeum by specimens found at Croyde Bay, the Strand near Ashford, and in the churchyard near Pilton. I have found what is probably the same species, a new one, at a high level in the Etroeungt Beds between Ratingen and Velbert in Germany.

Favosites is rare in North Devon and absent on the Continent.

The Pilton Beds are extremely rich in Echinoderms, such as *Pentremites*[5] and *Lepidesthes*, which are typically Carboniferous genera. They are unknown in Belgium, Northern France, and the Aachen district, but are well represented near Ratingen.

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[1] Phosphatic nodules are apparently not uncommon in the Pilton Beds. I have seen them at Bradford, near Pilton, and north-east of Landkey.

[2] *Pleurodictyum* is common here.

[3] Whidborne, 1896, p. 173, pl. xxi, figs. 4 and 5.

[4] Ibid., p. 11, pl. ii, figs. 5 and 8, ? 6–7.

[5] As W. E. Schmidt has pointed out, "*Pentremitidea*" *phillipsi* Whidborne is a synonym of *Pentremites ovalis* Goldf. "Die Echinodermen des deutschen Unterkarbons," *Abhandl. Preuss. Geol. Landesanst.*, Neue Folge, Heft 122, 1930, p. 65.

The Bryozoan fauna of the Pilton Beds seem to be very similar, if not identical with those of the Continent.

Brachiopods.—*Dalmanella* is the most common representative of the *Orthinae*, but *Schizophoria* is also frequent on the Continent. The latter was not known from North Devon until the writer discovered a cast of a brachial valve of the genus north-east of Landkey. This is in a poor state of preservation and it is impossible to say with certainty whether it is *S. resupinata* or the earlier mutation, *S. striatula* (Schloth.).

The Productids are represented by the genera *Avonia* and *Buxtonia* just as on the Continent. *Avonia praelonga* (Sow.) is the most characteristic species of the group in all regions, but *Buxtonia nigra*,[1] though a very common species in France, Belgium, and Germany, is unknown in England.

Productella is well represented in North Devon both by costate (*P. caperata* Sow.)[2] and smooth forms (*P. goergesi* Paeckelmann).[3] *P. caperata* and its variety *radiata* Paeck. are common at Ratingen and Velbert, as well as in North Devon, but seems to be wanting in Belgium and France. For *P. goergesi* see footnote [3].

Thomasina and *Krotovia*, very rare in Germany, are absent in North Devon and France. The first genus was discovered by the writer in the Comblain-au-Pont Beds of Belgium in the main outcrop.

The Spirifers have a distinctly Devonian aspect. *Spirifer tornacensis* is absent and so is *S. julii*, one of the most characteristic species on the Continent.

Lamellibranchs are common in the Pilton Beds, but are very rare in France, Belgium, and the Aachen district. They are of frequent occurrence at Ratingen and Velbert.

Goniatites are very rare both in England and on the Continent. *Imitoceras denckmanni* Wedekind has been found near Barnstaple and Fremington, and the writer has found some specimens of a small goniatite at Gerlimpont in Belgium. He has also found an *Imitoceras* between Ratingen and Velbert.

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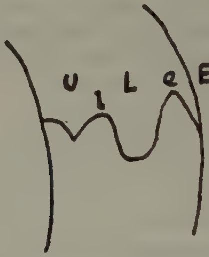
[1] In a paper shortly to be published in the *Abhandlungen der Preussischen Geologischen Landesanstalt*, I have shown that the median septum of the brachial valve of this species is bifurcate.

[2] This species was for a long time considered to be identical with *P. productoides* (Murch.).

[3] Paeckelmann described this species from the country around Ratingen and Velbert, " Die Fauna des deutschen Unterkarbons. Teil 2," *Abh. Preuss. Geol. Landesanst.*, N.F., Heft 136, 1931, p. 56, Taf. 2, figs. 1–2. It was not known in Belgium, France, and England until the writer found it in abundance in several outcrops in Belgium on the River Ourthe and near Florennes, between Sambre and Meuse. He has also a specimen from Semeries, in North France. The species is not uncommon in a small quarry on the right-hand side of the small valley north-east of Landkey, east of Barnstaple, where I have found several specimens. *P. goergesi* may be considered to be one of the most characteristic fossils of the lowest Tournaisian in North-Western Europe.

Clymeniae have not been identified with certainty from Devonshire, but a doubtful *Clymenia* has been found at a high horizon in the Pilton Beds, south of Barnstaple.[1] They are not uncommon in the highest part of the series in the North French area and form a thin band at the same high level between Ratingen and Velbert in Germany. It is extremely interesting to note that the doubtful *Clymenia* from North Devon was found near the upper limit of the Pilton Beds. Although I have very carefully searched the outcrops of the Comblain-au-Pont Beds of Belgium and the Aachen area, bed by bed, I have not seen a single specimen of *Clymenia*. I am therefore almost certain that *Clymeniae* are not represented in Belgium and near Aachen. They are also unknown south-east of Velbert.

The ? *Clymenia* found by Mr. Hamling, of which Mr. Tregelles has sent me a photograph, is an extremely evolute form, 19 mm. in its greatest diameter, with ribs on the earlier whorls. Parts of the outer portion of the suture are to be seen (Text-fig. 1). Describing this from right to left, the external saddle (e) is sharp and runs down to a broad and rounded lateral lobe (L). The lateral saddle (l) is also rounded but narrower than the lobe previously mentioned. Between the lateral saddle and the inside of the shell, a broad and pointed umbilical lobe (U) is seen.



TEXT-FIG. 1.—? *Clymenia* sp. Highest part of the Pilton Beds, hole north of Mount Sandford, south of Barnstaple. Specimen collected by the late Mr. Hamling and preserved in the Torquay Museum. Diagram illustrating external part of the suture.

Although it is highly probable that the fossil is a *Clymenia* and not a goniatite, one cannot be certain without examining the original specimen and observing the position of the siphuncle.

The species is quite different from the characteristic *Clymeniae* of the Continental Etroeungt Beds (*Cymaclymenia euryomphala*

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[1] *Proc. Geol. Assoc.*, xxi, 1910, 458. I was unable to see the specimens during my visit to North Devon, owing to the death of Mr. Hamling, a few days before, and to the absence of Mr. Tregelles, but since my return to Germany Mr. Tregelles has very kindly sent me photographs.

Schindewolf MS.) and differs from *Cymaclymenia* in its extremely evolute shell and deep external lobe.

Trilobites.—The following species are found in the Pilton Beds: *Phacops* (*Phacops*) *accipitrinus accipitrinus* (Phill.), *Brachymetopus woodwardi* Whidb., and *Phillipsia hicksi* Whidb.

The first is a very characteristic fossil of the lowest Tournaisian of North-Western Europe. In North France and Belgium, it is represented by the subspecies *Phacops* (*Phacops*) *accipitrinus maretiolensis* R. et E. Richter,[1] and near Aachen by *Phacops* (*Phacops*) *cornelius* R. et E. Richter.[1]

The genus *Brachymetopus*, which for a long time was considered to be entirely Carboniferous, was in 1926 described by R. and E. Richter from the Laevigites-Clymenia beds of the Lower Loire in West France. The genus is also known from the highest Etroeungtian beds of Velbert, but the species there, is distinct from *B. woodwardi.*

Whidborne records *Phillipsia hicksi* from the shore near Fremington, Pottington, Braunton Road, and Pilton. In the last two localities, however, only pygidia were found, and the determination of these as *Phillipsia* is thus doubtful. The Fremington specimen came from the highest level in the Pilton Beds, which I consider to be a little younger than the Etroeungt beds of the Continent. The specimen from Pottington consisted of a glabella only, nevertheless its determination as *Phillipsia* seems to be correct. Pottington is situated about three-quarters of a mile north of the Culm boundary.

The genus *Crytosymbole*, discovered by the author in the lowest Etroeungt Beds of the Velbert area, is not known from the Pilton Beds, nor from Belgium, North France, and the Aachen neighbourhood.

Algae.—Calcareous algae have not been found in North Devon, but *Solenopora* has been described from the Etroeungt Beds of North France by Delépine, and has been found in great abundance near Aachen by the present author.

THE ETROEUNGT BEDS OF NORTH FRANCE.

The Famennian shales and sandstones grade upwards into the Etroeungt Beds which have a thickness of about 150 feet. This zone consists of dark impure limestones and calcareous shales, with thin intercalations of sandy micaceous shales. Corals and stromatoporoids are abundant. At several places *Clymenia* occurs in the uppermost beds. Brachiopods abound, but lamellibranchs are rare. *Phacops* is one of the most characteristic fossils, particularly in the highest beds of the zone.

The Etroeungt Beds thin away in a northerly direction and in Belgium become the Comblain-au-Pont Beds.

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[1] R. and E. Richter, *Die letzten Phacopidae.* See "Literature".

THE COMBLAIN-AU-PONT BEDS OF THE BELGIUM AND AACHEN AREAS.

Three provinces are to be distinguished, viz. :—

(1) The Dinant and Aachen basin.
(2) The southern margin of the Namur basin.
(3) The northern margin of the Namur basin.

(1) In the Dinant and Aachen basins, the Comblain-au-Pont Beds are very similar to the Etroeungtian of North France, from which they are only distinguished by the absence of *Clymenia* and by their thinness—they are only 70–80 feet thick. In the Aachen district the beds are crowded with rugose corals and stromatoporoids.

(2) On the south side of the Namur basin the beds are considerably thinner and are frequently without fossils. Limestones are less well represented, the zone consisting mainly of shales and sandstones.

(3) Further north, in the north crop of the Namur basin, the beds have thinned out to great extent. The Hastière Limestone, which in the southern area immediately overlies the Comblain-au-Pont Beds, is represented in the Samme Valley by soft limestones with algae, ostracods, and *Eumetria*. These have a very similar assemblage to the K Beds at Bristol, particularly to K 1, and may well be the equivalent of that sub-zone. The K Beds, which were considered by Vaughan to be Upper Famennian to Comblain-au-Pont age, contain *Syringothyris* and *Dictyoclostus vaughani*, both unknown in the Pilton, Etroeungt, and Comblain Beds. The Hastière Limestone must be in part equivalent to higher parts of the K zone (K 1 and K 2) of the Bristol area, Mitcheldean, and South Wales, and the Comblain-au-Pont Beds may thus correspond to the Modiola phase at the base of K (Km) or to the uppermost part of the Old Red Sandstone.[1]

THE ETROEUNGT BEDS OF THE COUNTRY AROUND RATINGEN AND VELBERT.

The Etroeungtian in the vicinity of Velbert and Ratingen is of considerable interest in considering the correlation of the Pilton Beds. The upper part of the sequence is very similar to the Etroeungt Beds of North France, but is of considerable thickness, reaching about 3,500 feet. The uppermost part of the zone is built up of oolites with thin layers of calcareous shales passing laterally into fine crystalline argillaceous limestones with ostracods, in a westerly direction, and into nodular calcareous shales in an easterly one. The lower 1,200–1,500 feet have a distinctly Pilton aspect. The strata consists of bluish-grey micaceous slates, calcareous sandstone and lenticles of impure crinoidal limestone. They succeed bluish micaceous slates of Famennian age. Southwards the beds become progressively thinner, passing laterally into the so-called Hangenberg-Schiefer of Westphalia—a cephalopod facies.

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[1] *Ctenacanthus* sp. has been found near the top of the Old Red Sandstone at the Cement Works Quarry, Mitcheldean. It is true that the spine was obtained from a loose block, but this is identical with beds exposed in the side of the quarry lying 5 to 10 feet below the lowest bed of Carboniferous shale. See T. F. Sibly and S. H. Reynolds, *Quart. Journ. Geol. Soc.*, 1937, p. 28.

PALAEOGEOGRAPHY.

(See Text-fig. 2.)

The following three facies provinces can be distinguished in the south of England :—

(1) South Devon, where the Pilton beds are represented by the *Entomis* Shales—a cephalopod facies.

(2) North Devon, in which a brachiopod facies (the Pilton Beds) is well represented and is of considerable thickness.

(3) North shore of the Bristol Channel, where the Pilton Beds are represented by an Old Red Sandstone (non-marine) facies.

In North France, Belgium, and the Aachen district are rocks of very definite thickness and distinct lithology corresponding to the Pilton Beds. These thin out in a northerly direction. The Old Red Sandstone is unknown in Belgium, but at the north crop of the Namur basin there is a break between the Famennian and the Lower Carboniferous, and it may be that Old Red Sandstone facies was deposited during Famennian time, but was entirely removed by denudation before the Dinantian was laid down. It is probable that the palaeogeographical position of the Belgian province is represented in England by a region lying between the outcrops of the Pilton Beds in North Devon and the south coast of Wales. This area, which is narrow in Britain, extends in an east-south-easterly direction and attains its greatest width in the latitude of Dinant. The palaeographical equivalent of the Pilton Beds in the latter region seems to have lain in the French Ardennes, where the Carboniferous has been removed by denudation, but where there were probably beds with a Pilton assemblage succeeded by Culm cherts. North France shows closer affinity with North Devon than with Belgium, both in the lithology of the lower part of the Etroeungt Beds and in the presence of *Clymenia*. The absence of the Pilton facies in Belgium and at Aachen is probably due to the cephalopod facies lying farther away from this region than it was from North Devon, North France, and Ratingen.

On the right bank of the Rhine, in the Velbert and Ratingen district, beds laid down during Pilton time pass laterally into a cephalopod facies. Thickness, petrology, and fauna all point to the area representing a palaeogeographical zone which lay between the developments of North France and North Devon. Although

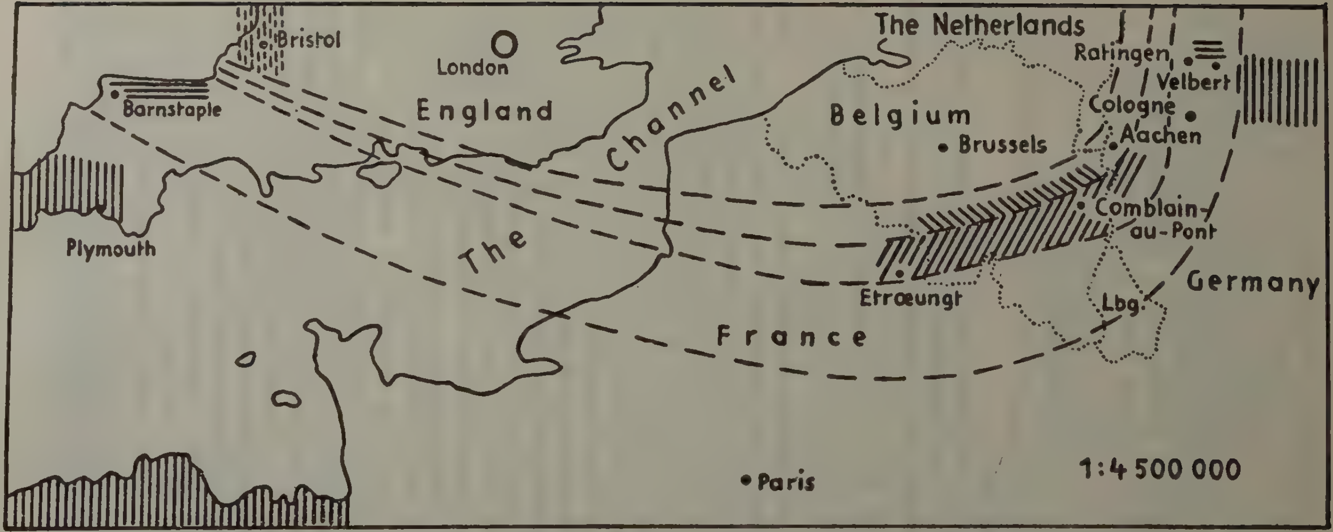

Fig. 2 Map showing facies development during Pilton time.

▥ Cephalopod facies ▤ Pilton facies ▨ Comblain-au-Pont facies
▧ Namur and Pembroke facies ▦ Old Red facies

Carboniferous Limestone succeeds the Etroeungt Beds, the Middle and Upper Tournasian was probably represented by a Culm facies, as I have pointed out in my paper dealing with the Viséan transgression. In Lower Viséan time, however, Carboniferous Limestone conditions very generally replaced the Culm facies. At the beginning of Lower Devonian time cephalopod (Hercynian) conditions were gradually replaced by a brachiopod (Rhenish) facies, but these developments were reversed in many areas during the passage of the Tournasian into Viséan. It is an interesting fact that the Etroeungt Beds of Ratingen pass up into brachiopod-bearing shales equivalent to the Hastière Limestone of Belgium in the same way as the Pilton Beds do in North Devon.

We are thus able to recognize in North-Western Europe the following facies zones from south to north :—

(1) The cephalopod development, represented in South Devon and in Westphalia, south-east of Velbert.

(2) The Pilton facies as in North Devon and partly near Ratingen, which bears a close resemblance to the development in North France.

(3) Comblain-au-Pont facies connected with (2) by the North French facies.

(4) Namur facies, seen in the south crop of the Namur basin, and probably also developed in South Pembrokeshire.

(5) Old Red Sandstone facies, represented over most of England, and was probably developed on the Brabant massif, though removed by denudation.[1]

I wish to express my best thanks to Mr. Fred A. Brokenshire, of Barnstaple, Mr. Inkerman Rogers, of Bideford, Mr. Tregelles, of Barnstaple, and Dr. Stanley Smith, who have so kindly helped me during my studies in England. Dr. Smith has been good enough to revise my manuscript and send it to the press.

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[1] It is hardly necessary to add that this is merely a suggestion and that actual conditions may have been somewhat different.

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The Formation of Laterite.

By D. W. BISHOPP.

IF the term "laterite" is restricted to apply only to hydrates of iron, aluminium, or in special cases manganese, formed by katamorphic processes, then obviously a great deal of what we commonly term "laterite" is incorrectly named. I am assuming that laterite is the end or apical product of a process of rock degradation which may stop short at the formation of the hydrated silicates—clays or lithomarges—or continue right on to hydrate according to chemical and physical environment and nature of the parent rock. Harrison's studies of deposits in British Guiana show that lithomarge and bauxite are associated with each other in all possible proportions, with or without the hydrates of iron (which does not appear to pass through a secondary hydrated silicate or "kaolin" stage), and free silica, which on one occasion has been recorded in the form of tridymite. These substances are mixed in all degrees, and can only be distinguished by laboratory tests. The point which decides whether one of such rocks should be classed as a laterite or a lithomarge seems to be quite arbitrary, unless it is agreed that a laterite should contain an excess of hydrates over hydrated silicates.

Mr. Scrivenor (GEOL. MAG., June, 1937) objects to Dr. Fox's "hypothesis" that the hydrated silicate of aluminium is only a stage toward the formation of the hydrate. Dr. Fox's work is unfortunately not accessible to me at this time and place; but there are so many examples available of rock degradation at all its stages, that this "hypothesis" must surely be regarded as a matter of observed fact rather than inference. The question is why, in the case of granitic rocks, there is an apparent inhibition of katamorphism at the point of kaolin, whereas with sub-acid and alkali types the process goes right on to the formation of hydrates. Perhaps it is a balanced reaction which depends upon the amount of free silica present, and other factors such as alkaline solutions which have been mentioned. It seems that kaolin originally derived from the felspars of granite will undoubtedly bauxitize provided always that the excess of finely-divided silica can be conveniently removed; not otherwise. Dr. E. C. Harder (*Canadian Institute of Mining and Metallurgy*, 1936), in writing of bauxite deposits in British Guiana, points out that certain selective solvents are necessary to remove compounds other than those of aluminium, thus causing the concentration of the latter in situ. This is the process of "differential enrichment" described by W. J. Hughes and myself in connection with deposits of manganese oxides and hydrates on the Gold Coast (*Trans. Inst. Mining and Met.*, 1930). It involves not only reactions which may be reversible, but the purely physical process of solution and redeposition, at different rates, of the various elements present in the system. There are so many local factors taking part in the superficial concentration of iron, manganese, and aluminium, that exact connection between cause and effect is hard to trace. To the economic geologist, however, it is the degree of concentration that is important. For every one concentration of this type whose degree is defined by the arbitrary line "payable", there are enormously greater and widely spread distributions of lower tenor. The favoured instances of high concentration seem to owe their richness to the disturbance of a general equilibrium-point or constant rate of change by the preponderance or absence of some particular factor; and if, for example, Mr. Scrivenor's granite-clay equilibrium in Malaya has not been upset since early Pleistocene times, we may have to wait for ever for a general change to hydrate.

The manganese deposits of Insuta in the Gold Coast are enormously richer than any others in that country, though it is full of manganese-bearing rocks. The question was, what factor or combination of factors was disturbing the normally slow rate of change, and making the opposed processes of concentration and dispersion balance toward the "concentration" end of the scale.

There seem to be insufficient data available to enable the correspondence between tonnages and degrees of concentration to be worked out for these supergene occurrences in any one deposit or petrographic province. In British and Dutch Guiana the quantity of "high-grade" bauxite has been estimated at $1 \cdot 6 \times 10^8$ tons; it is not known how much of the lower grades of bauxitized material exists in conjunction with this, except that there is a great deal. There is a vastly greater quantity of associated aluminous rock-degradation products which are barely or not at all bauxitized. Is there a relationship between intensity of concentration and quantities of material based on chance; or on some law analogous to that governing change in radio-active material?

In the field, high-grade bauxite most commonly occurs in beds lying upon beds of kaolin, with a fairly sharp line of demarcation between them, except that a network of tubes and veins of bauxite penetrate the clay a little below the base of the bauxite bed. This refers to occurrences in British Guiana and Surinam: more detailed descriptions are given by Dr. E. C. Harder (op. cit.) and Dr. R. Ijzerman (*Geology and Petrology of Surinam*) respectively.

This question of equilibrium in supergene deposits has a strong analogy with that in the growth of plants: some members of a batch will shoot ahead, and others delay or fail; and since it is by no means certain that some concentrations of iron and manganese are not in part at any rate due to biochemical processes, it may well be that there is some question of biochemical equilibria bound up with these surficial concentrations. What indeed are the "special solvents" which come into action? In the case of granite, is not the apparent "inhibition at the point of kaolin" possibly due to the potash-hunger of plants which would prevent this alkali from taking further part in the katamorphic process, whereas the soda-lime requirements are not so great?

I am indebted to the Conservator of Forests, British Guiana, for the apparently well-established observation that Determa-forest is closely associated with bauxitic areas east of the Essequibo River, and that these trees are generally of rare occurrence outside them. Determa is more common in Dutch Guiana, but its relation with the Surinam bauxite areas is not yet known. To what extent can certain types of vegetation accelerate or retard processes of bauxitization?

The periodic concentration and dispersion of certain elements on the earth's surface—for example carbon, iron, and calcium—seem to be closely related to their cyclic combination with various forms of living matter: which sorts them out after the fashion of Maxwell's Demon, or a thermionic valve. In dealing with the origin of surface deposits of manganese, iron, or aluminium, is a mechanistic or a vitalistic explanation to be preferred? Can it be said that laterites, as we know them to-day, could have formed in pre-Cambrian times, in the absence of living material? If the answer is "probably not", oecology and biochemistry must be invoked to solve the problem.

The Zonal Position of the Elsworth Rock and its Alleged Equivalent at Upware.

By W. J. Arkell, New College, Oxford.

1. THE AGE OF THE ELSWORTH ROCK OF ELSWORTH AND ST. IVES.

SEELEY to the last maintained his original view that the Elsworth Rock was in the Oxford Clay.[1] Hudleston, Roberts, and H. B. Woodward correlated it with the Lower Calcareous Grit, though Woodward went so far as to admit that "the occurrence in the Elsworth Rock of the Lower Corallian *Ammonites perarmatus* and the Upper Corallian *A. plicatilis* might be taken to indicate the local blending of the two zones".[2] Rigaux (1892, p. 47), after a visit to the Sedgwick Museum, appears to have been the first to correlate it on palaeontological grounds with rocks of Upper Corallian (*plicatilis* zone) age, the Calcaire d'Houllefort in the Boulonnais and the Corallian limestones of Headington. It was Wedd, however, who proved the contemporaneity of the Elsworth and St. Ives Rocks and their Upper Corallian age, by mapping the outcrop and stressing "the great abundance of ammonites of the *plicatilis* type" in both. His verdict was that "the Elsworth and St. Ives Rock belongs to a somewhat higher horizon than the Lower Calcareous Grit" (Wedd, 1901, pp. 83, 85).

The idea that the fauna of the Elsworth Rock represents a "blending" of the *cordatum* or *perarmatum* and the *plicatilis* zones permeates the literature. The abundance of *Serpulae*, as Wedd pointed out, denotes slow deposition. The presence of *Serpulae* stuck on internal casts of ammonites, Wedd thought, "may point . . . to possible erosion and reconsolidation". According to Fearnsides (1904, p. 14), "the commonest fossils are the ammonites of the *Plicatilis* type, together with almost all the ammonites of the highest Oxford Clay."

In 1931 I wrote (1933, p. 413), "since the deposit must be dated by its latest fossils, there seems no alternative but to correlate it with the Berkshire Oolite Series" (*plicatilis* zone), but I repeated the supposition that some of the ammonites were of *cordatus* age, and I was also influenced by certain lamellibranchs not found in Corallian Beds elsewhere in this country (e.g. *Parallelodon keyserlingii* d'Orb. sp., *Nucula oxfordiana* de Loriol). At that time I had not studied the ammonites, and I would not now attach much importance to the lamellibranchs. Since the Elsworth Rock represents a peculiar lithological facies, it is to be expected that it would contain some species of lamellibranchs not met with elsewhere.

Later the same year Spath (1933, pp. 866–7), published a list of ammonites from the Elsworth and St. Ives Rocks and wrote as follows: "They are all referable to the *transversarium* and *perarmatum* zones, i.e. the Argovian, with, perhaps, only a few large *Cardioceras* of the *excavatum* group worked up from the underlying Upper Oxford Clay, with *C. suessi* Siemiradzki, the condensed seam of Elsworth Rock being everywhere underlain by a *Serpula* bed, denoting a pause in sedimentation. The evidence of the ammonites from the well near the inn at Upware (see Wedd. 1898, p. 609), is confirmatory; for the species from the undoubted Oxford Clay include *Cardioceras scarburgense* and *C. praecordatum* (*renggeri* zone), and in the higher transitional beds (with brown oolite grains), in addition to *Peltoceratoides* spp., there are such typical *cordatum* zone fossils as *Cardioceras rouilleri* Nikitin, *C. nikitinianum* Lahusen, and *C.* (*Goliathiceras*) *korys* Buckman sp."

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[1] See discussion of Wedd's paper, 1901, p. 84.

[2] Ibid.

Through the kindness of Mr. A. G. Brighton and the Geological Survey officers I have been able to borrow and study all the available ammonites from the Elsworth and St. Ives Rock, and so benefit by direct comparison with the extensive fauna of large ammonites from Oxfordshire, Berkshire, and Wiltshire in Oxford University Museum and my own collection. At first sight the assemblages seem very different, for the Elsworth and St. Ives ammonites are nearly all small and can be contained in three or four drawers, while an equal number of specimens from the Oxford-Wilts outcrop fill a small room. There is, however, enough material of the large Oxford species of *Perisphinctes* and *Aspidoceras* at different stages of incompleteness (whether due to youth or breakage) for it to be possible to connect nearly all the Elsworth and St. Ives species with them. It is significant that the only large examples from Elsworth and St. Ives are extremely fragmentary. It appears that the Elsworth and St. Ives ammonite collections are "pseudo-micromorphic". The small size of the exposures and the lack of any regular excavating of the stone in large pieces has led to artificial selection of nuclei and young. The process may have been furthered by some peculiarity of preservation causing unusual lack of cohesion in large and heavy specimens. The Argovian assemblage from Chézery and La Faucille, Department of Ain, described by Ronchadzé (1917), is suspected of having undergone similar unconscious artificial selection.

Only when the ontogenies of the large British species are understood, through comparing specimens at all ages, can the small Elsworth and St. Ives forms be assigned to their proper places; though even then closely allied species are often indistinguishable at such small diameters (e.g., *P. cotovui* and *P. pickeringius*, or *P. buckmani* and *P. auriculatus*). The following is the list of identifications:—

AMMONITES FROM ELSWORTH AND ST. IVES ROCK.

C = common (five or more specimens).
M = moderately common (three or four specimens).
R = rare (one or two specimens).

Perisphinctes.	*Elsworth.*	*St. Ives.*	*Oxford.*
P. (*Dichotomosphinctes*) *buckmani* Arkell	R	R	C
P. (*Dich.*) *auriculatus* Arkell			
P. (*Dich.*) *antecedens* Salfeld	M	R	C
P. (*Dich.*) *rotoides* Ronchadzé	R		C
P. (*Dich.*) *ouatius* Buckman	C		R
P. (*Dich.*) sp. nov., aff. *ouatius*	M		R
P. (*Dich.*) *gresslyi* de Loriol	C	C	
P. (*Perisphinctes*) *chloroolithicus* (Gümbel) (=*tumulosus* Buckman)		R	C
P. (*Arisphinctes*) *maximus* (Young and Bird)	C		C
P. (*Aris.*) *cotovui* Simionescu (= *ariprepes* Buckman)	C	C	C
P. (*Aris.*) *pickeringius* (Young and Bird)	C	C	C
P. (*Aris.*) sp. nov., aff. *pickeringius*	M	M	R
P. (*Aris.*) *plicatilis* (J. Sowerby)	C	C	M
P. (*Aris.*) sp. nov., aff. *subrota* Choffat	M	R	C
P. (*Kranaosphinctes*) *cymatophorus* (Buckman)	R		C
P. (*Kran.*) *decurrens* (Buckman)	M		M
Aspidoceras.			
A. (*Euaspidoceras*) *akantheen* Buckman	M	R ?	M
Cardioceras.			
C. (*Cawtoniceras*) *maltonense* (Young and Bird)	C	C	R
C. (*Cawt.*) *cawtonense* (Blake and Hudleston)	C	C	R
C. (*Cawt.*) sp. nov., aff. *cawtonense*	R	R	
C. (*Cawt.*) *highmoori* Arkell	R	?	R
C. (*Cawt.*) cf. *kokeni* Boden		M	R
C. (*Cawt.*) *schellwieni* Boden	R ?	M	
C. (*Cawt.* ?) cf. *vagum* Ilovaisky	M	R	R
C. (*Scoticardioceras*) cf. *excavatum* (J. Sowerby)	R	M	C
C. (*subgen. nov.*) *zenaidae* Ilovaisky	C		R
C. (*subgen. nov.*) *densiplicatum* Boden	M	R	C
C. (*subgen. nov.*) *sowerbyi* Arkell	R ?		M
Goliathiceras.			
G. *galeatum* Buckman	R	R	M
G. sp.	R ?		
Oppelids.			
Ochetoceras canaliculatum (v. Buch)	R	R	
Trimarginites henrici (d'Orbigny)	M	R	
T. sp. cf. *henrici* (*mendax* Seebach sp. ?)	R		

Under the combined genera *Perisphinctes* and *Aspidoceras* (*Euaspidoceras*), there are only two names common to this list and Spath's. The reason is that already mentioned, the impossibility of naming such small specimens without understanding the ontogenies of the large species from Oxford, Berks, and Wilts. In particular, when these are understood, the Indian and Bolivian elements in Spath's list melt away. The horizontal range of none of the species is known to extend beyond Rumania, Poland, European Russia, and Portugal, but some of the Cardiocerates may extend to Northern Siberia and Greenland, and *Ochetoceras canaliculatum* has been figured from South and Central America.

Under the Cardiocerates and Oppelids agreement is not so bad. Most of the species do not grow to such large sizes. Nevertheless, there is still much detailed work to be done on these families, and the present list is only provisional. It can, however, be said definitely that all the forms of Cardiocerates are of late type and nearly every species occurs in the *plicatilis* zone of the Oxford district. This applies to the *excavatum* group as much as to the others, and I can find no specimens that indicate an earlier age or suggest derivation.

The Oppelids have been found nowhere else in England, but they occur in the normal shelly Corallian facies of the *plicatilis* zone all over Europe, and as close to England as both Normandy and the Hanover district. *Ochetoceras canaliculatum* is represented by the equally widely-distributed variety *hispidum* (Oppel), which some consider a different species.

The only species of *Aspidoceras* is one found in the *plicatilis* zone in Oxfordshire and Berkshire. *A. catena* has not been found, and so the *catena* zone cannot be specifically included in the Elsworth Rock, for there is no other ammonite which is characteristic of the zone where typically developed, at and near Marcham, Berkshire. Study of foreign collections in the past year has revealed that in Normandy and North-West Germany where there is no separate *catena* zone the species occurs in the *plicatilis* assemblage, in matrix and preservation indistinguishable from the rest. Hence I am inclined to regard the abundance of *A. catena* about Marcham as a local epibole of little significance in wider correlation, and to assimilate the epibole in the *plicatilis* zone rather than the underlying *cordatus* zone. Occasional finds of other ammonites in the *catena* beds of Berkshire tend to support this conclusion.

There remain only the *Serpulae* on ammonite casts, referred to by Wedd. As he stated (though not quite as he meant), the casts with *Serpulae* are all of ammonites "of *plicatilis* type, not older Oxfordian fossils". Similar casts of Perisphinctes with *Serpulae* and *Exogyrae* attached occur in the *plicatilis* zone about Oxford (the holotype of *P. cymatophorus*, Buckman, 1923, pl. cdl, A, B, is one). The casts are perfectly fresh and show no signs of attrition or re-working, which would necessarily be present if the shells had been removed by erosion after the solidification of the filling and surrounding matrix. The result must therefore have been produced by differential solution and recementation. As is well known, ammonite shells were probably of aragonite and those of oysters and *Serpulae* were of calcite.

The conclusion is that the Elsworth and St. Ives Rock is a homogeneous deposit belonging wholly to the *plicatilis* zone, in which nearly all its ammonites occur in neighbouring areas. The abundance of fossils, the ironshot lithology, and the prevalence of *Serpulae* and encrusting oysters indicate slow deposition. The probability is that it is a condensed deposit representing a large part of *plicatilis* time.

2. IRONSHOT CLAYS BELOW THE ELSWORTH ROCK AT ELSWORTH, AND THEIR FAUNA.

In the winter 1931–2 a party of Cambridge students dug a trial hole at Elsworth with the object of collecting zonally from the Elsworth Rock and the beds above and below it. The site chosen was a field belonging to the rector, south of the school and between Brook Street and Workhouse Lane, on the outcrop of the Elsworth Rock as mapped by the Geological Survey. The hole had to be refilled and the turf replaced. I am greatly indebted to Mr. A. G. Brighton, who sponsored this excavation, for giving me the particulars and for lending the material obtained. It includes just over 100 ammonites or fragments of ammonites. Thanks are also due to Mr. R. H. S. Robertson who organized and led the enterprise, and to the Rector of Elsworth for allowing his land to be used.

The following description of the beds was left with the fossils in the Sedgwick Museum in 1932, and to it I have added my identifications. The clays are more or less oolitic throughout, the ooliths

SECTION IN TRIAL PIT AT ELSWORTH.

Beds.		ft.	in.
B	Drift [?] weathered yellow. Full of Elsworth Rock fossil sand some others, as well as pieces of sandstone and quartz porphyry.	5	6
C	Clay, rather oolitic, disturbed at top		6
	Limestone nodules, fairly fossiliferous.		
D	Clay, marly, slightly oolitic, weathering brick-red along joints; also joints full of gypsum.	1	1
	Limestone nodules, *Gryphaea* band.		
E	Clay, blue, oolitic, with larger gypsum crystals. Fossils rare except for *Gryphaea*	2	2
F	Clay, paler, grey, oolitic, much more fossiliferous. Oysters and lamellibranch casts. *Cardioceras* cf. *anabarense* Pavlow and *C.* indet.		
	Limestones, continuous band, nearly unfossiliferous		4
G	Clay, blue, nearly non-oolitic		9
H	Clay, much more oolitic. *Cardioceras costellatum* Buckman, *C. quadrarium* Buckman, *C. costicardia* Buckman (about forty specimens of these three spp.), *Goliathiceras sidericum* (Buckman), *Goliathiceras* sp. (minute nucleus), *Aspidoceras nikitini* Borissjak (two large fragments). *Procerithium muricatum* (J. Sowerby)	1	3
	Limestones, continuous band. Nearly unfossiliferous		4½
J	Clay, oolitic. *Cardioceras costellatum*, *C. quadrarium*, *Aspidoceras* sp. (minute nucleus)		10
	Limestone		6
K/L	Clay, oolitic. *Cardioceras costellatum*, *C. quadrarium*, *Goliathiceras korys* (Buckman), *Peltoceras* (*Peltoceratoides* ?) sp., *Perisphinctes* sp. indet. (two crushed fragments and one fragment of mould), *Lopha gregarea* (J. Sowerby)		6
	Limestone, almost continuous band		3
X	Clay, non-oolitic, blue, with pyritized fossils (unexamined; none kept ?)		
	Total of beds C to L inclusive	8	6½

rust-coloured. The hole was dug in a slight depression near the bottom of the field, and my own impression is that the spot chosen was on the site of an older excavation, perhaps a quarry, from which the Elsworth rock had been removed, and that bed B is debris. Mr. E. E. L. Dixon agrees that bed B is probably debris, not Drift.

Beds J, K/L together yielded about forty-five specimens or fragments of specimens of *Cardioceras costellatum* and *C. quadrarium*, and perhaps also nuclei of *C. costicardia*, and bed H another forty. Many of them are small, at a stage at which these three species are indistinguishable. Almost every one can be matched exactly with one of the well-preserved limonitic casts from the Upper Oxford Clay of the type-locality, Studley brickyard, near Oxford, whence I have a fairly large number. (For the original figures see Buckman, 1925, pl. dcxvi, A, B; 1926, pl. dcxc; pl. dcxxxiii.) The small nuclei of *Goliathiceras* from bed H can also be matched from the same pit at Studley, and at least one of them is identifiable as *G.* ("*Hortoniceras*") *sidericum* Buckman, of which the type came from there (Buckman, 1922, pl. ccxcvi).

Beds K and L yielded nine fragments of casts and moulds of *Peltoceras* too small for identification, agreeing equally well with *P.* (*Peltoceratoides*) *constantii* (d'Orb.), *P.* (*Parawedekindia*) *arduennense* (d'Orb.), and *P.* (*Peltomorphites*) *williamsoni* (Phillips).

Only one Cardiocerate is different from any known from the Oxford Clay of Studley, namely, one from bed F. This is too small to identify directly with the original figures of *C. anabarense* Pavlow (1913, pl. xvii, figs. 2 *a*, *b*), a species described from Siberia, but it is identical with some of intermediate size from the Lower Calcareous Grit of Steeple Ashton and Calne, Wiltshire, which connect with the Siberian species. *Aspidoceras* (*Euaspidoceras*) *nikitini* Borissjak (1908, p. 79, pl. ix, fig. 1), described from the *cordatus* zone of the Donetz, which is represented by two large fragments from bed H, also occurs in the Lower Calcareous Grit of Calne.

Hence it is evident that the 8½ feet of ironshot clays encountered in the trial pit belong to the *cordatus* zone, which is the highest zone of the Oxford Clay at Oxford, and is represented by Lower Calcareous Grit in Yorkshire and in part also in the Calne-Seend district of Wiltshire. The beds must underlie the true Elsworth Rock as exposed in the village street, a sequence which is independently suggested by the Elsworth Rock fossils in bed B at the top of the trial section.

The questions of stratigraphical nomenclature raised by these beds have been discussed with Mr. A. G. Brighton and Mr. E. E. L. Dixon, who is revising the mapping and preparing a memoir on the adjoining area to the south, and the conclusions reached owe much to the expression of their views. Since the ironshot clays of the *cordatus* zone are mapped with the Elsworth Rock and the facies is similar, it seems desirable to include them in an expanded Elsworth

Series, although the *cordatus* zone at Elsworth contains no "Rock" properly speaking. Wedd used the expression Elsworth Series in his important papers in 1898 and 1901, and it is probable that the *cordatus* beds were included in the strata grouped with the Elsworth Rock by Seeley, though from then until 1931 no one had seen them exposed.

If this terminology be accepted, it must be emphasized that at Elsworth the Elsworth Series embraces two distinct zones, those of *cordatus* and *plicatilis*, that there is no sign of admixture, that the Elsworth Rock proper is wholly of *plicatilis* date, and that the current view that the Rock contains earlier elements is based on misidentifications of the later Cardioceratid ammonites.

3. THE SO-CALLED ELSWORTH ROCK AT UPWARE.

Wedd (1898, p. 609) published a well-section near the inn at Upware, in which he assigned 16 feet of strata to the Elsworth Series, consisting of two bands of ironshot impure limestone, separated by 9 ft. 9 in. of clay. The lower limestone band was 4 ft. thick and yielded most of the fossils. It rested upon clay, penetrated to 4 ft. 6 in., which was assigned to the Oxford Clay. The same beds were also proved by excavating in a ditch nearly ¼ mile south of the inn.

Wedd stated : " Considering the strong lithological and palaeontological resemblance between this Upware rock and the types at Elsworth and St. Ives . . . there can be no doubt of the correctness of the correlation of this Upware rock with that of Elsworth and St. Ives." He recorded also that H. Keeping " examined the material thrown out from the well, and . . . at once recognized the Elsworth Rock, with Oxford Clay below ".

Spath (1933, p. 867), who examined the ammonites in 1931, wrote, " at Upware, the Elsworth rock is in close association with a local reef of Coral Rag and Coralline oolite which also yielded typical Argovian species ", and in the paragraph quoted above (p. 446), he stated that the evidence at Upware was confirmatory of that at Elsworth and St. Ives. From the " higher transitional beds with brown oolite grains " at Upware, however, he recorded three " typical *cordatus* zone fossils ", whereas at Elsworth and St. Ives, whence twenty times more ammonites were available, he had not been able to name a single species older than the *transversarius* (*plicatilis*) zone (see above, p. 446).

Mr. A. G. Brighton has kindly sent me on loan all the ammonites from the Upware well and ditch that are preserved in the Sedgwick Museum. In view of the passages just quoted, great was my surprise to find no *plicatilis* zone species among them.

These six identifiable species merit a little further discussion. The time is opportune, for I have on loan from Caen University, by

Ammonites from Elsworth Series at Upware.

Name.	*Registered Numbers (Series J.)*	*Previous published identifications* (W. = Wedd, 1898, p. 610; S. = Spath, 1933, p. 867).
Cardioceras costellatum Buckman	337, 334–5 341	*A. vertebralis* (W.) *A. cordatus* (W.) *A. mariae* (W.) *C. rouilleri* (S.)
Cardioceras ? quadrarium Buckman	293	*A. vertebralis* (W.)
Cardioceras cf. *nikitinianum* Lahusen	339	*C. nikitinianum* (S.)
Cardioceras indet.	291–2, 340	*A. cordatus* (W.)
Goliathiceras goliathum (d'Orbigny).	338	*A. goliathus* (W.)
Goliathiceras korys (Buckman)	336, 343	*A. mariae* (W.) *C. korys* (S.)
Peltoceras (*Peltomorphites*) *williamsoni* (Phillips)	295	*A. eugenii* (W.) *Peltoceratoides* spp. (S.)
Ditto ? (minute nucleus)	296	

the kindness of Professor L. Dangeard, a small collection of Cardiocerates selected from the wealth of material available at Caen from the Oolithe ferrugineuse (*cordatus* zone) of the Normandy coast.

Cardioceras costellatum and *C. quadrarium* Buckman (see above, p. 450). The Upware Cardiocerates are all poorly preserved, but the five named above, so far as they go, bear the closest comparison with comparable-sized specimens from the Elsworth trial hole, and from the limonitic Upper Oxford Clay (*cordatus* zone) of the type-locality, Studley brickyard, near Oxford. I have also collected the species in the Red Nodule Beds of the Upper Oxford Clay on the Dorset coast, and at least *C. costellatum* is abundant in the Oolithe ferrugineuse of Normandy. A specimen is represented (wrongly named), in pl. x, fig. 21, of Douvillé's monograph (1912) (reproduced in pl. xxxvii, figs. 1, 2, of my *Jurassic System*, 1933).

Cardioceras cf. *nikitinianum* Lahusen (1883, pl. v, figs. 7, 8, 9). The specimen (J. 339) so identified by Spath is a fragment of ribbed body-chamber very like Lahusen's Fig. 7, but the ribs are less coarse. The Upware fragment, on the other hand, agrees exactly with complete specimens from the Oolithe ferrugineuse, which are more involute than Lahusen's species. I suspect that *C. costellatum* and its allies produce body-chambers indistinguishable from these larger forms (all body-chambers have perished at the type-locality, Studley). Further opinion is reserved until the *cordatus* zone fauna has been worked out more thoroughly. There are innumerable forms and few definite dividing lines between them.

Goliathiceras goliathum (d'Orbigny). This species is represented by a well-preserved fragment from the ditch-excavation. It is near to *Goliathiceras galeatum* Buckman (1920, vol. iii, pl. clvi), from the St. Ives Rock, which also occurs in the Elsworth Rock (Sedgwick Museum, No. J. 214), but the venter is a good deal flatter and the ribbing rather stronger. The Upware fragment agrees exactly with a complete specimen from the Oolithe ferrugineuse of Trouville now before me, and that is probably a topotype, for it in turn agrees perfectly with d'Orbigny's smaller syntype (1849, p. 519, pl. cxcvi, figs. 1, 2). The *Renggeri* Marls of the Jura bernois contain a comparable species, "*Macrocephalites*" *greppini* de Loriol (1898, pl. v, fig. 15), but that becomes smooth at a smaller size.

Goliathiceras korys Buckman (1922, vol. iv, pl. ccclxi). One of the two specimens of this species is the best-preserved of the ammonites from the well, and it agrees closely with the holotype, from the Oxford Clay of Loch Staffin, Isle of Skye. Comparable forms occur in the Yorkshire Lower Calcareous Grit (Ball Beds) and the Red Nodule Beds of Weymouth. A poorly-preserved specimen was obtained also from bed L of the trial hole at Elsworth (above, p. 449).

Peltoceras (*Peltomorphites*) *williamsoni* (Phillips). The specimen (J. 295) is fragmentary, but enough is preserved to show that it is identical with the holotype of *Ammonites williamsoni* Phillips at present on loan from the Scarborough Museum, and with the inner whorls of a large topotype also on loan from the Yorkshire Museum, York. Both come from the Scarborough Lower Calcareous Grit. *Peltomorphites hoplophorus* Buckman (1925, vol. v, pl. dlxiv), from the Weymouth Upper Oxford Clay (*cordatus* zone), is thought to be the same species, but the holotype is specifically undeterminable (Geol. Survey Museum, No. 47568).

Thus the eight or ten specifically determinable ammonites obtained from the so-called Elsworth Rock of Upware, assignable to six species (two queried), belong without exception to the *cordatus* zone (as used in its original sense ; see Arkell, 1936, pp. 151–2).

The Upware and Elsworth *cordatus* zone fauna correlates satisfactorily with the Oolithe ferrugineuse of the Normandy coast, where the lithology is also identical (see Raspail, 1901) (the thickness at Villers is 29 feet). The ironshot facies is developed also in Kent (Lamplugh, Kitchin, and Pringle, 1923, pp. 213–14). In Oxfordshire the contemporary deposit is a grey clay with limonitic ammonite casts. In Dorset it is grey clay with red-coated mudstone nodules and red-coated casts of lamellibranchs and ammonites. In Normandy (Trouville) not only the *cordatus* zone but also the basal part of the *plicatilis* zone (Oolithe de Trouville) is developed in the ironshot facies.

4. Where is the true Elsworth Rock at Upware?

Two fragments identified above as *Cardioceras costellatum* Buckman (Nos. J. 334–5) came from the (sparsely ironshot) clay between the two ironshot limestone bands in the Upware well (Wedd's bed C, 1898, p. 609). The upper ironshot limestone band (bed E) yielded the specimen of *Goliathiceras goliathum* (d'Orbigny in the ditch excavation. Hence all the beds B to E inclusive in the well-section (16 feet) belong to the *cordatus* zone. The layer of corals (*Thecosmilia annularis*) at the very top (on bed E) suggests the base of the *plicatilis* zone; and Wedd stated that bed E of the well-section must be the same as his bed 1 of the section in a field north of the inn yard (p. 606), which was proved immediately below the Lower Coral Rag of the Coralline Oolite. Hence there seems no room for the Elsworth Rock as such.

Now since the Elsworth Rock at Elsworth and St. Ives is believed to be a condensed deposit, in which is concentrated in a few feet apparently all the *plicatilis* zone except for that part which is represented by the basal layers of the Ampthill Clay (at, for instance, Gamlingay and Swavesey), Elsworth Rock should not be expected in its typical form in places where the *plicatilis* zone is fully developed. In other words, the Elsworth Rock cannot be the condensed equivalent of the *plicatilis* zone in one place and at the same time underlie the normally developed *plicatilis* zone in another. Rigaux had the courage in 1892 to correlate the Elsworth Rock with the Headington limestones about Oxford, and the logical conclusion to be drawn from the above evidence is that it expands similarly at Upware and (with the Gamlingay Clay) is represented by the Upware Coralline Oolite and Lower Coral Rag. Those rocks have long been correlated with the *plicatilis* zone oolites and rag about Oxford.

This conclusion is supported by the ammonites. Thanks again to Mr. Brighton, I have been able to compare the material with

AMMONITES FROM UPWARE CORALLINE OOLITE.

	No. loc.	*N. pit.*	*S. pit.*	*Br. pit.*	*New pit.*	*St.I., El.*	*Ox.*
Per. (*Dichotomosphinctes*) *buckmani* Arkell .			1	2		?	x
P. buckmani or *P. antecedens*	2					x	x
P. (*Dichot.*) *antecedens* Salfeld . . .		2			1	x	x
P. (*Dichot.*) *gresslyi* de Loriol . . .		1				x	
P. (*P.*) *chloroolithicus* (Gümbel) (= *tumulosus* Buckman)	1		?1		1	x	x
P. (*P.*) *parandieri* de Loriol			1				x
P. (*Arisphinctes*) *maximus* (Young and Bird) .		1				x	x
P. (*Aris.*) *pickeringius* (Young and Bird) .				1		x	x
P. (*Aris.*) sp. nov.				1			x
Asp. (*Euaspidoceras*) *paucituberculata* Arkell .		1					x
Card. (*Cawtoniceras*) *maltonense* (Young and Bird)			7			x	x
C. (*Cawt.*) *cawtonense* (Blake and Hudleston) .			1			x	x
C. densiplicatum Boden				1		x	x
	Unlocalized	North Pit	South Pit	Bridge Pit	New Pit	Elsworth and St. Ives	Oxford

Numbers indicate the numbers of specimens known.

Mr. Brighton informs me that Bridge Pit and New Pit may mean either of two pits close together.

the Oxford collections. There are only twenty-six identifiable specimens, mostly fragmentary, but there is the normal numerical relation between large and small specimens, not disturbed by artificial selection as at Elsworth, and the general aspect of the assemblage is consequently more like that from the Oxford district.

With two-thirds of the species represented by only a single specimen, it is obvious that only the merest sample of the full fauna is known, and any single chance find is likely to add to the list. Nor are the numbers of specimens even approaching adequate for differentiating in age between the rocks exposed in the several pits.

5. The Oxford Clay at Upware.

From the 4 ft. 6 in. of Oxford Clay penetrated below the ironshot beds in the Upware well (Wedd's bed A, 1898, p. 609), there are in the Sedgwick Museum some twenty recognizable ammonites, of which about eleven are identifiable specifically. The list is as follows :—

Name.	*Registered Numbers (Series J).*	*Previous published Records* (W. = Wedd, S. = Spath).
Quenstedtoceras scarburgense (Young and Bird) . . . . . *Q. praecordatum* Douvillé . . .	301–8 344	*A. cordatus* (W.) *C. scarburgense* (S.) *C. praecordatum* (S.)
Q. omphaloides (J. Sowerby) . .	294	*A. mariae* (W.)
Perisphinctes cf. *vesuntina* Maire .	318	——
Peltoceras sp., cf. *interscissum* Uhlig, de Loriol (1898, pl. vii, fig. 18) .	313–17	*A. biplex* (W.)
Peltoceras (*Parawedekindia*) ? *arduennensis* (d'Orb.)	309	*A. eugenii* (W.)
Peltoceras s.l., sp. or spp. indet. .	310–11, 297	*A. biplex* (W.)
Hecticoceras (*Lunuloceras*) sp. indet.	345	——

The specimen of *Quenstedtoceras omphaloides* (No. J. 294) is labelled " *Q. mariae*, Elsworth Rock Series ", and it accounts, in part at least, for Wedd's record of *Q. mariae* from that series. But the matrix and preservation are quite different from any of the other ammonites from the Elsworth Series, and agree exactly with those of a *Peltoceras* (J. 309) labelled Oxford Clay. The specimen compares with the topotype from the Weymouth Oxford Clay figured by Buckman (1921, vol. iii, pl. cxcv), which from its pyritic state of preservation cannot have come out of the *cordatus* zone and must have come from either the *mariae* or the *lamberti* zones. It is probably the same as de Loriol's *Cardioceras goliathus* of 1898 (pl. ii, fig. 14), and his *Quenstedtoceras sutherlandiae* of 1900 (pl. iii, fig. 10) may be only a variety.

This assemblage can be assigned at once to the *mariae* zone, which was the zone found also in the well at Fen Stanton brewery

(Wedd, 1901, p. 79), the fossils of which I have examined in the Geological Survey Museum. The same zone is well exposed and abundantly fossiliferous in the brickyards at Warboys, Hunts, and Akeman Street Station, Bucks, and in the lower part of the cliff between Shortlake and Redcliff Point in Dorset, where the *cordatus* zone with red kidneystones can be seen in place above it. The commonest element in the fauna is the species-group of *Quenstedtoceras scarburgense* (Young and Bird) and *Q. praecordatum* R. Douvillé. The original fragmentary syntypes of *Q. praecordatum*, from Villers (Douvillé, 1912, pl. x, figs. 10–20, *non* figs. 21–3), comprise several varieties, some of which are indistinguishable from the holotype of *Q. scarburgense* figured (enlarged three times) by Buckman (1924, vol. v, pl. dviii). Douvillé's later " beaux représentants " (1913, p. 364, pl. vii, figs. 6, 7), topotypes, are somewhat more compressed and more carinate than the holotype of *scarburgense*, and one at least is finer-ribbed. These forms all occur together, however, and when enough material is collected it seems unnecessary to regard them as anything more than varieties. Judging by collections of the contemporary assemblage from Warboys, Upware, Bucks, Oxford (Summertown), and Dorset, the species embraces the *Cardioceras cordatum* of de Loriol's figs. 4 to 9 from the Jura bernois (1898, pl. ii) and figs. 3, 5, 6 from the Jura lédonien (1900, pl. iii).

Quenstedtoceras mariae (d'Orbigny) is not present in the small collection from Upware, but it and the similar variable species-group (connecting with *Q. omphaloides* Sowerby) are second only to *Q. scarburgense* in abundance at Warboys, Akeman Street, and in Dorset. De Loriol's *Jura bernois*, Figs. 1 and 2 (1898, pl. iii), represent, perhaps, the most typical of this group, but the ribbing is often denser than in those. The reasons for using *Q. mariae* as zonal index for this zone in preference to *Q. praecordatum* = *scarburgense* or *Creniceras renggeri* have been explained elsewhere (Arkell, 1936). They are grounds of priority and precision. From de Loriol's plate ii (1898) alone, it is obvious that the *renggeri* beds include both the *mariae* and *cordatus* zones, and *C. renggeri* has since been shown to have a long vertical range. Difficulties over the exact identity of the holotype of *Q. mariae* do not affect the priority of the species as zonal index.

The Peltocerates from the *mariae* zone in the Upware well are too small and imperfect for definite determination. At young stages the subgenera *Peltoceratoides*, *Peltomorphites*, and *Parawedekindia* are indistinguishable. The specimen (No. J. 309) recorded as *A. eugenii* by Wedd, however, is identical with some small fragments collected by me in the *mariae* zone between Shortlake and Redcliff Point in Dorset. There is close agreement with the nucleus (syntype) of *Peltoceras* (*Parawedekindia*) *arduennense* (d'Orbigny) (1848, p. 500, pl. clxxxv, figs. 6, 7). The nucleus of *P.* (*Peltomorphites*) *eugenii* Raspail (see d'Orbigny, 1848, pl. clxxxvii, figs. 1, 2) is much more evolute. The nearest among the forms figured by de Loriol is his *P. arduennense* (1898, pl. vii, figs. 1–3), but in the English specimens the ribs bifurcate closer to the umbilicus. *P. intertextum* (Simpson), from Yorkshire (refigured, Buckman, 1926, pl. dclxii), is the same but for higher proportion of bifid ribs. Five fragments of a larger specimen or specimens (J. 313–17) may belong to the same species, but one shows rather more strongly rursiradiate ribbing, suggestive of *Rursiceras*. The style of the ribbing is as in de Loriol's *P.* cfr. *interscissum* Uhlig (de Loriol, 1898, pl. vii, fig. 18).

6. SUMMARY OF CONCLUSIONS.

(1) The Elsworth Rock of Elsworth and St. Ives is a condensed deposit belonging to the *plicatilis* zone.

(2) There is no evidence that it contains any ammonites derived from earlier zones. Statements that it does are based on misidentifications.

(3) The Elsworth Rock at Elsworth overlies at least 8½ feet of ironshot clays with thin bands and nodules of limestone, the clays containing abundant ammonites of the *cordatus* zone and no others.

(4) The so-called Elsworth Rock at Upware is the equivalent of the ironshot *cordatus* zone developed below the Elsworth Rock at Elsworth.

(5) The true Elsworth Rock (*plicatilis* zone) is represented at Upware by the Coralline Oolite and Lower Coral Rag.

(6) For convenience in stratigraphical nomenclature it is desirable to group together the condensed ironshot *cordatus* and *plicatilis* beds of Elsworth as the Elsworth Series.

(7) The Elsworth Series, as defined in 6, corresponds with the Oolithe ferrugineuse and the greater part of the Oolithe de Trouville on the Normandy coast. At Trouville the *plicatilis* zone to some extent combines the developments at Elsworth and Upware.

(8) The ironshot *cordatus* zone was proved in the Upware well to rest directly upon normal clays of the *mariae* zone, and the same zone was proved in the vale below Elsworth in the Fen Stanton brewery boring.

I am greatly indebted to Mr. E. E. L. Dixon and Mr. A. G. Brighton for criticisms and suggestions, and especially to Mr. Brighton for the trouble he has taken in sending me all the fossils on loan and supplying the relevant information.

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Intrusions of the Glen Falloch Area.

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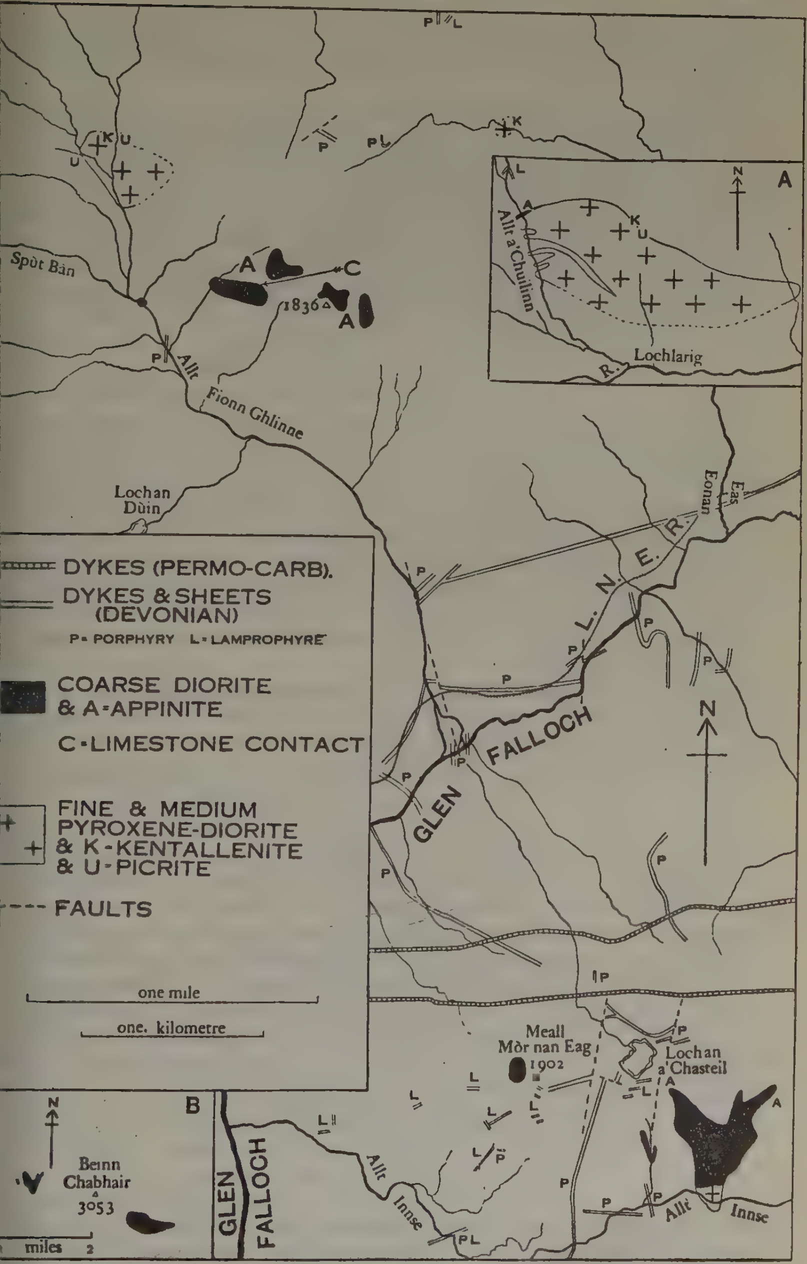
1. Introduction.

RECENT work in the Glen Falloch area has revealed that certain small masses shown as diorite on 1 inch Sheet 46 of the Geological Survey (Scotland) contain rocks belonging to the kentallenite and appinite suites. As these intrusions have not been previously mentioned in geological literature it has been considered worth while placing a short description on record.

The intrusions, which may be regarded as belonging to the " Newer Granites ", can be divided into two sets: (*a*) that to the north-west of Glen Falloch, about 4½ miles west-south-west of Crianlarich, and (*b*) that to the south-east of Glen Falloch, including a small group north of the Allt Innse (Text-fig. 1), and a somewhat isolated mass (Text-fig. 1, insets A and B) farther to the east. Those of set (*a*) are injected into a variety of Dalradian rocks including garnetiferous



TEXT-FIG. 1.—Intrusions of the Glen Falloch Area. Inset A (same scale and ornament): Intrusion north of R. Lochlarig. Inset B: Sketch-map indicating relative position of intrusion shown in Inset A.

mica-schists, the Loch Tay limestone, "green beds," and epidiorite, while those of set (*b*) cut only the albite-mica-schists of the Ben Ledi Group.

The rocks of these intrusions closely resemble types from the Arrochar complex to the south-west, described by the author in a previous communication (1935, *b*), to which the present paper may be regarded as a supplement. In the field it is possible to distinguish a fine to medium-grained pyroxene-rich diorite (cf. fine and medium diorites of Arrochar complex), a coarse hornblende-rich diorite (cf. coarse diorite of Arrochar complex), kentallenite, picrite, and appinite. Throughout the region occur sheets and dykes of porphyry and lamprophyre.

2. FIELD DESCRIPTION.

Set (*a*) :—In the Allt Fionn Ghlinne, 550 yards above its confluence with the Spùt Bàn, fine diorite is seen almost in contact with epidiorite. The fine diorite passes northwards into a medium-grained diorite which makes up the bulk of the intrusion mapped in this locality. Near the north margin, however, there is a passage first into the kentallenite and then into picrite of somewhat coarser grain. At the western margin, in a tributary, picrite may also be seen in contact with quartzose schist. The junction appears to be clean cut, with but little veining of the schist, or of inclusion of the country-rock by the igneous rock.

On Sheet 46 diorite is shown in the Allt Fionn Ghlinne for some distance below the Spùt Bàn. A tiny exposure of decomposed coarse diorite occurs where a small tributary joins the main stream just below the Spùt Bàn, but with this exception the section is entirely in pure cream-coloured limestone and in "green beds".

Small intrusions occur at between 1,400 feet and 1,900 feet above sea-level to the north-east of the Allt Fionn Ghlinne. Exposures are confined to scattered outcrops on the steep hillside and the shape of the intrusions and the distribution of the Dalradian rocks they cut must largely be a matter of conjecture. This group of intrusions almost entirely consists of appinite, varying considerably in basicity, though a portion of the most westerly is composed of an acid rock of hybrid appearance. The country rock is mainly garnetiferous mica-schist, but one of the intrusions (Text-fig. 1) is in contact with the Loch Tay limestone, which is noticeably altered to a calc-silicate hornfels. A little to the south-east of this contact a sharp junction may be seen between appinite and epidiorite.

Farther to the north a small mass of diorite, cut off by a fault, is shown on Sheet 46. This outcrop is merely a porphyry sill. A small exposure of fine diorite, grading into fine-grained kentallenite at the east margin, occurs in a headstream of the Eas Eonan, and is cut at a small waterfall by a sheet-like mass of granite. Between this small intrusion and two dykes shown at the extreme upper edge of Text-fig. 1, there occurs a rather peculiar area in which the schist is greatly disturbed and brecciated and injected by veins of lamprophyre and porphyry which are not large enough to be mapped.

Porphyry sheets may be well seen in the railway cuttings near the mouth of the Allt Fionn Ghlinne.

Set (*b*) :—Fine to medium diorite is exposed in the Allt Innse, south-east of Lochan a'Chasteil. A few outcrops of similar rock occur a little to the north of the stream, followed by a gap in exposure beyond which is seen coarse diorite rich in hornblende. Contacts with baked schist may be studied at several localities. At two of these the diorite a few feet from the margin passes rather irregularly into very coarse appinite. The schist is injected for a few inches by felspathic material from the igneous rock, but as is the case with all the intrusions described in the present paper there is very little inclusion of the country rock.

Coarse diorite is also seen in a small intrusion a short distance to the west, and a coarse hornblendic rock, containing a fairly high proportion of felsic constituents, occurs on the western side of the summit of Meall Mor nan Eag. Minor intrusions, most frequently of a sheet-like nature, are fairly abundant in this region. An 11-ft. dyke in the Allt Innse, two-thirds of a mile south-south-west of Meall Mor nan Eag, can be shown to be multiple, with an earlier portion of porphyry or felsite and a central 3 feet of very fine-grained later spessartite.

The largest of all the masses which are the subject of the present paper is found some three miles to the east of those just described (Text-fig. 1, insets A and B). It lies on the north side of the valley of the R. Lochlarig and is most easily approached by the track which runs up that river from Loch Voil. In the Allt a'Chuilinn, fine or medium diorite forms what appears to be a number of sheet-like fingers injected into the schists, against which the igneous rock is definitely chilled. The northernmost contact in the stream, however, is between schist and several feet of appinite, the relationship of which to the diorite is not determinable. Scattered outcrops of fine and medium diorite occur for nearly a mile to the east of the Allt a'Chuilinn. The chief interest of the mass, however, is provided by rocky outcrops of rough-weathering kentallenite and picrite at the north margin just west of a conspicuous crag of schist. The exposures are not connected with each other or to the neighbouring diorite but kentallenite appears to occur nearest the margin and to pass southwards into the most basic type.

3. PETROGRAPHY.

For the author's views on the usage of the term diorite, reference should be made to a previous publication (1935, *a*, p. 250).

Coarse diorite :—All slices of this type examined were considerably decomposed. Hornblende is the dominant ferro-magnesian constituent and where fresh is brown in colour (6600).[1] Augite may also be present in fair amount, often as a core to the amphibole. Biotite is usually replaced by chlorite and epidote. Andesine, in laths up to 1·5 mm. in length, may be recognized ; owing to the alteration it is difficult to be sure whether there is an appreciable amount of orthoclase present. Quartz occurs interstitially and by an increase in its amount the coarse diorite may pass into quartz-diorite of the Tonale type (6624). On the other hand, increase in hornblende provides a passage into appinite.

Appinite :—The modes (volume percentages) of two typical examples are given below. The hornblende is of an olive-brown variety, sometimes greenish towards the edges of crystals which are frequently idiomorphic. Alkali-felspar is undoubtedly present, but owing to the characteristic decomposition only the total felspar is given in the mode. Some of the quartz is graphically intergrown with orthoclase.

	A.	B.
Felspar	25·2	29·1
Quartz	16·9	3·6
Hornblende . . .	56·7	63·6
Iron ore	1·2	3·7

A. Appinite (6619) : Hill-side, 1,380 yards east of confluence of Allt Fionn Ghlinne and Spùt Bàn.

B. Appinite (6583) : Allt a'Chuilinn.

These appinites are identical with specimens from the Arrochar complex. In dealing with the latter a list of other Scottish occurrences was given. To the literature of these may now be added a description of the hornblende-rich rocks associated with the Dorback Granite (Walker and Davidson, 1935, p. 50), and a recent paper on the Colonsay masses (Reynolds, 1936, p. 391).

Fine and medium diorite :—As opposed to the rocks just described, the characteristic mafic constituent of these types is pyroxene. A typical mode is given below (A). As regards grain-size it may be mentioned that in the medium-grained rocks the plagioclase laths vary from 0·5 to 1·0 mm. in length. A small amount of orthoclase and of quartz is included under plagioclase in (A). A fair amount of hypersthene occurs along with augite. In the medium diorite there is a tendency for an increase in the amount of orthoclase. This is shown by the second mode (B), given below, of medium-grained diorite from the mass north of the R. Lochlarig, near the kentallenite outcrop. Beautifully fresh, very fine chilled diorites may be collected from the edge of the same mass. These have an extremely finely crystalline groundmass with small porphyritic laths of andesine about 0·5 mm. in length, euhedral augites up to 2·0 mm. in diameter, and also well-shaped serpentine pseudomorphs after olivine (6590).

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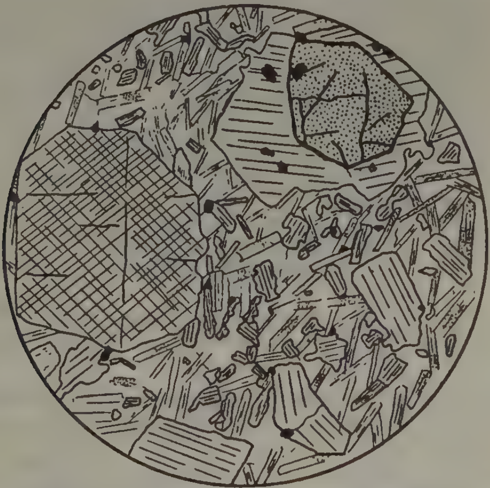
[1] Numbers in brackets refer to the catalogue numbers of thin sections in the collection of the Geology Department, University of Glasgow.

In one slice (6573) of medium diorite, from just north of the Allt Innse, there is clouding of the plagioclase of the contact type (MacGregor, 1931), which may indicate that the coarse diorite which makes up the bulk of the mass at that locality has come in later.

	A.	B.
Orthoclase . . .	—	9·3
Plagioclase . . .	63·0	47·7
Quartz . . .	tr.	—
Biotite . . .	3·8	7·8
Hornblende . . .	0·3	—
Augite . . .	29·8	34·1
Olivine . . .	3·1	1·1

A. Medium diorite (6581): Allt a'Chuilinn.
B. Medium diorite (6586): 950 yards west by north of confluence of Allt a'Chuilinn and R. Lochlarig.

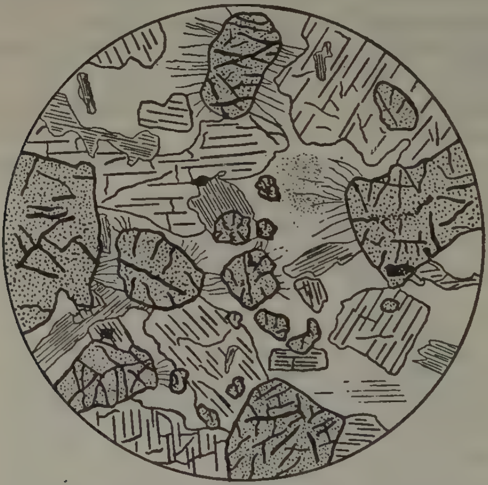
Kentallenite and Picrite:—The mode of kentallenite from the R. Lochlarig intrusion is given below (A). The plagioclase is andesine, in laths from 0·5 to 1·0 mm. in length, idiomorphic towards biotite and orthoclase. The amount of the latter is considerably lower than in the type kentallenite but the authors of the term (Hill and Kynaston, 1900, p. 540) do not lay any special emphasis on the relative proportions of the two felspars. With augite is included in the mode a certain amount of hypersthene. Both the pyroxene and the olivine have a porphyritic tendency. Apart from that contained in alteration cracks in the olivine there is very little iron ore, but apatite is quite an important accessory.



Text-fig. 2.—Kentallenite or pyroxene-monzonite: Allt Fionn Ghlinne, about 1,270 feet above O.D. Consists of orthoclase, plagioclase, augite, hypersthene, olivine, biotite, and iron ore. × 17.

The rock from the Allt Fionn Ghlinne mass (B, below) is at the extreme acid end of the suite and might well be termed a pyroxene-monzonite (Text-fig. 2). Orthoclase has risen to a high proportion, while the amount of olivine has greatly dropped. Along with augite there is an unusually large amount of hypersthene. This rock resembles a type from the Allt an t-Sithein in the Beinn Buidhe region to the west (Hill and Kynaston, 1900, p. 535).

A very fine-grained, beautifully fresh kentallenite comes from the tiny intrusion in the headstream of the Eas Eonan. The groundmass is formed of plagioclase laths about 0·25 mm. in length and abundant orthoclase. Augite occurs as idiomorphic phenocrysts about 1·0 mm. in diameter, while the fresh, optically positive, olivine crystals may reach 3·0 mm. across. Biotite is also well represented (6609).



TEXT-FIG. 3.—Picrite: Allt Fionn Ghlinne, about 1,300 feet above O.D. Consists of plagioclase, augite, hypersthene, olivine, biotite, and iron ore. × 15.

	A.	B.
Orthoclase	7·7	23·3
Plagioclase	32·8	30·9
Biotite	8·6	3·9
Augite	32·9	37·5
Olivine	18·0	4·4

A. Kentallenite (6587): On hill-side half a mile north of confluence of Allt a'Chaluinn and R. Lochlarig.

B. Kentallenite or pyroxene-monzonite (6569): Allt Fionn Ghlinne, about 1,270 feet above O.D.

In both the Allt Fionn Ghlinne and R. Lochlarig intrusions types occur which might equally well be described as mafic kentallenites or picrites (Text-fig. 3). Olivine becomes very abundant, as can be seen from the four representative modes given below, and is associated with rhombic and monoclinic pyroxene in varying proportions. Biotite is also well represented, except in the most basic example, and as in the kentallenites is moulded on the plagioclase (basic andesine). Alkali-felspar appears to be present but cannot be separated with sufficient certainty in every case to be differentiated in the mode. A slice (6601) from the north-west margin of the Allt Fionn Ghlinne intrusion is remarkable as showing a small amount of quartz.

	A.	B.	C.	D.
Plagioclase	25·3	17·9	20·4	10·8
Quartz .	1·0	—	—	—
Biotite .	14·5	14·4	11·5	3·0
Augite .	32·9	36·9	37·1	42·6
Olivine .	26·3	30·8	31·0	43·6

A. Picrite (6601): Half a mile north-north-west of confluence of Allt Fionn Ghlinne and Spùt Bàn.

B. Picrite (6570): Allt Fionn Ghlinne, about 1,300 feet above O.D.

C. Picrite (6588): Hill-side 850 yards north of confluence of Allt a'Chuilinn and R. Lochlarig.

D. Picrite (analysed rock, 6589): Hill-side 820 yards north of confluence of Allt a'Chuilinn and R. Lochlarig.

The most basic of the picrites has been analysed. Much of the olivine, which is partly serpentinized, occurs as very numerous small rounded crystals enclosed in the augite and hypersthene. The noteworthy features of the analysis are the very high proportion of magnesia and the low content of alkalies. It will be seen that as regards the latter the dominance of potash, characteristic of the kentallenites, is preserved. It has not been found possible to discover any very close parallel of the analysis.

			Norm.	
SiO_2	44·22	Or	2·22	
Al_2O_3	4·46	Ab	1·05	
Fe_2O_3	3·85	An	10·56	
FeO	6·73	Di	11·95	22·57
MgO	25·08		9·30	
CaO	8·06		1·32	
K_2O	0·44	Hy	22·10	25·27
Na_2O	0·13		3·17	
H_2O+	5·65	Ol	21·70	25·27
H_2O-	0·80		3·57	
TiO_2	0·22	Mt	5·57	
P_2O_5	0·11	Il	0·46	
MnO	0·18	Ap	0·34	
CO_2	*Nil*	H_2O	6·45	
	99·93		99·76	

Picrite (6589): Hill-side 820 yards north of confluence of Allt a'Chuilinn and R. Lochlarig. Anal. W. H. Herdsman.

Types such as the picrites just described are absent from the Arrochar area, but occur in the well-known Garabal Hill intrusion (Scott and Wyllie, 1913, p. 250) where, however, kentallenite has not so far been discovered. In their passage into picrite the kentallenites of the present area resemble those of Glen Orchy (Kynaston, 1908, p. 93).

Porphyries and lamprophyres:—All the dykes and sheets of the region are in a decomposed state but the rocks present nearly all appear to be referable to one or other of the above, typical porphyrites of intermediate composition, such as are characteristic of the Etive and Ben Nevis dyke swarms, being practically absent. In this respect the resemblance to the Arrochar complex is again close (Anderson, 1935 *b*, p. 273), though in the present region there is a higher proportion of the acid hypabyssal rocks.

Contact rocks:—With the exception of the limestone the contact metamorphic effects which can be ascribed to the intrusions are not striking. In the field it can be seen that the pelitic and semi-pelitic schists are indurated and lose their typical silvery lustre up to 50 feet from the margin, while in their respective zones the albites are reddened and the garnets replaced by dark aggregates. Under the microscope an increase in the amount of biotite at the expense of muscovite, chlorite, and iron ore can be observed, while some of the muscovite also appears to have gone to form felspar, which is now very sericitized as are the albites of the regional metamorphism. The garnets are replaced by biotite-quartz-magnetite aggregates. In no case were any specifically contact minerals observed.

As regards the epidiorites and " green beds ", no changes which could be definitely ascribed to thermal metamorphism were noted.

Quite striking effects, on the other hand, may be observed in the limestone at distances limited to perhaps 30 feet from the contact with appinite. The limestone is very variable, even within a few inches, but a specimen 50 feet from the contact may be taken as a fair average of the unaltered rock. In addition to the dominant granular calcite there occurs a fair amount of quartz, biotite, chlorite, and muscovite, and also some magnetite. In the altered rocks diopside occurs throughout, usually in pale green to colourless grains. Felspar also commonly occurs and appears to be mainly orthoclase. In a slice 10 feet from the contact, in which there persists a fair amount of free quartz but practically no calcite, wollastonite is abundant as small laths. The same slice (6633) shows prehnite, which is probably secondary as it is confined to a well-defined band crossing the slide. In another slice (6632) 5 feet from the contact, in addition to diopside and wollastonite, there occur large porphyroblasts of grossularite associated with xenoblastic idocrase (cf. Walker and Davidson, 1935, p. 57). The rock actually in contact with the appinite is very rich in diopside but shows no other contact minerals, the other constituents being quartz, a little calcite, and abundant felspar, possibly partly derived from the igneous rock. The latter shows both at the main contact and in veins penetrating the limestone *lit-par-lit* fashion, contamination in the presence of very abundant apatite (Nockolds, 1933, p. 563) and of some sphene, and in the local addition of green irregular crystals of hornblende to those of the appinite. There is no evidence, however, that this contamination spreads for more than a few inches.

5. CONCLUSIONS.

It is not proposed to enter into any detailed discussion on the origin of the rocks described. Such a discussion, the author feels, should await further work on the components of the Lower Old Red Sandstone igneous complexes of the South-West Highland province. The following significant points may, however, be mentioned.

As was shown by Hill and Kynaston in the Beinn Buidhe region (1900, p. 541), a connection can be traced in the present area between kentallenite and diorite. The region, in fact, supplies excellent confirmatory evidence of such a connection in the occurrence of orthoclase-rich pyroxene-diorites and olivine-poor kentallenites. Further, the kentallenites are closely associated geographically, as in Colonsay (Wright and Bailey, 1911), the Ballachulish region (Bailey, 1916, p. 166; Walker, 1927), and Arrochar (Anderson 1935 *b*), with appinite. Further, it is shown by means of a new analysis that the kentallenite possesses an ultra-basic facies.

In view of the proximity of most of the appinite of the region to the outcrops of the Loch Tay limestone, it would be tempting to grant the latter a role in the formation of the hornblende-rich igneous rock. The occurrence of appinite at contacts which cut only pelitic schist, and in the Arrochar complex, to mention only one region remote from any limestone outcrop, shows that such a view must be treated with very great caution.

As in the Arrochar complex, it would appear that the appinite represents a special facies of the coarse and the kentallenite of the fine and medium diorites. In Arrochar local evidence was obtained that appinite cut medium diorite but doubt was cast on the view that this age-relationship persisted throughout the complex. No direct evidence of age-relationship was obtained in the present region. It is possible that at the time of emplacement both the hornblende-magma and the pyroxene-magma were available, to be injected according to circumstance to form in general the coarse diorite and the fine and medium diorite respectively, with appinite locally produced from the first and kentallenite from the second. The conditions under which these special types were brought into existence, and, in fact, the origin of the two magma types must, however, be a subject for future work.

5. ACKNOWLEDGMENTS.

The author wishes to express his indebtedness to Dr. G. W. Tyrrell of Glasgow University for help throughout the preparation of the paper, to Mr. W. R. Flett of the same for assistance in the

field, and to Professor D. E. Innes of St. Andrews University, where much of the microscope study was carried out, for the use of a Wentworth recording stage. Thanks are also due to the Geological Survey for affording every facility for examining relevant field maps, to the Carnegie Trust for a grant to cover the cost of the analysis, and to the Institute of Quarrying for the use of the blocks of Text-figs. 2 and 3.

6. LIST OF WORKS TO WHICH REFERENCE IS MADE.

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Sandstone "Dykes" in the Dodoma District of Tanganyika Territory.

By W. H. Reeve.

1. Introduction.

SANDSTONE "dykes" have not previously been noted in Tanganyika Territory.[1] Those described below were observed by the writer while engaged in regional mapping in the Dodoma district during 1936.

The entire area mapped is underlain by one of the younger type granites which may be correlated with the Younger Granite of South Africa. These are distinguished from the older gneissic granites of pre-Muva-Ankolean age (= Old Granites of South Africa) and the ancient ortho-gneisses by the absence of foliation.

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[1] Since completing this paper, the writer has referred to an account by F. P. Mennell (*Int. Geol. Cong., Compte Rendu, XV Session, South Africa*, 1929, vol. ii, pp. 281–2) of sandstone "dykes" in the Sumbadzi River which

The younger granite has invaded rocks of the Basement Complex and directional features have been produced in those places where it has been contaminated by partial or complete assimilation of the basic members of that system and the streaking out of xenoliths. Directional features are also found in localities where shearing has taken place along zones of fracture subsequent to the consolidation of the magma. Both these processes have produced such characters in the granite along the Fufu scarp and the term " schistosity " will be used to distinguish the directional tendency in the granite from the true foliation displayed by the older gneisses.

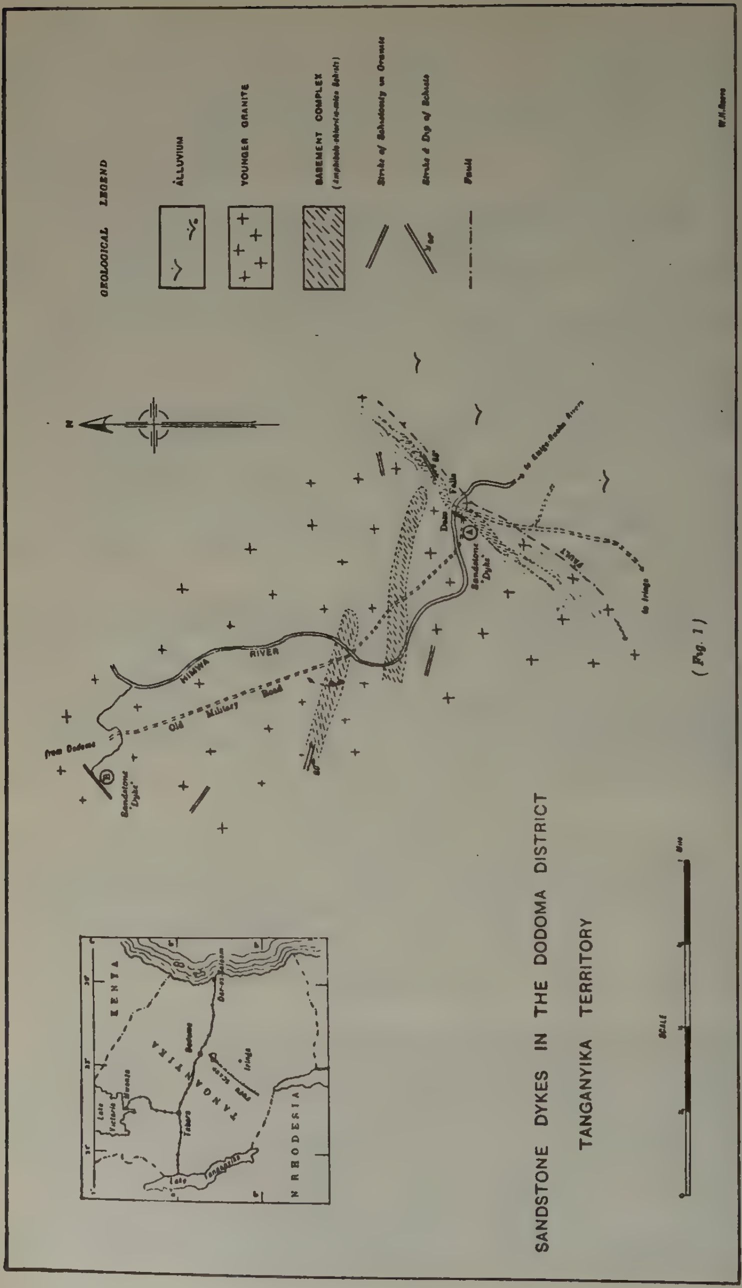
The Fufu scarp is one of the physiographic features of this Territory which have resulted from the latest tectonic movements correlated with the rift zone fractures. While the granite along this scarp shows the impress of a north-east shear, probably long antedating the Rift period, the general direction of the more ancient lines of shear and foliation elsewhere in this region is dominantly east to east-south-east. It would appear, therefore, that the Fufu fault scarp, which strikes approximately north-east, is the result of renewed stresses of comparatively recent date, relieved along an old line of weakness in the crust.

The extreme youth of this fault scarp is indicated by the rejuvenation of the Bubu, Himwa, and Kisigo Rivers, all of which descend the scarp by falls, and by the existence on top of the scarp at its north-east extremity of a " perched " *mbuga*, a shallow alluvial depression characteristic of peneplain regions, which in pre-Rift times was probably co-extensive with the wide alluvial plain of the Ruaha drainage system to the south-east.

2. FIELD OCCURRENCE.

About fifty-four miles south of Dodoma, the Himwa River descends the Fufu scarp by a series of falls, at the head of which a small dam has been constructed. An old German military road, connecting Dodoma with Iringa and the south, traverses the scarp close by the falls. At this place, the contaminated and schistose granite is in contact with a thin band of basic basement schists. Observations

joins the Rufiji River at the sharp easterly bend about ten miles below the Ruaha-Rufiji confluence in Eastern Tanganyika Territory. The " dykes " occur a few miles above the Sumbadzi-Rufiji junction and exhibit features comparable with those of the " dykes " described here. In width, they range from less than an inch to over two feet. They are usually nearly vertical and contain inclusions of the country rocks which Mennell believes to have fallen from above into the fissures, now occupied by the dyke, at the time they were being filled with sand. The Sumbadzi " dykes " lie in Karroo shales and are associated with irregular, impersistent patches of sandstone. The inclusions are mainly of Karroo shales; the " dykes ", therefore, are at least post-Karroo. Those of the Dodoma district, on the other hand, are in granite and are believed to be possibly of late Tertiary or early Quaternary age.



TEXT-FIG. 1.—Field relations of the Sandstone Dykes.

of the dip and strike of the schists and of schistosity of the granite indicate a shear zone just below the southern edge of the dam. The first " dyke " (A) was found at the contact of granite and schists (Text-fig. 1).

The rock appears to fill a crack or fissure at the contact. It was first noted in the rock wall west of the old military road about a hundred yards south-west of the dam, where it is 7 or 8 inches thick. Its strike is 60° (magnetic) and it can be followed across the road and down the bank of the Himwa to the water channel, a gradual decrease in its thickness being apparent. The strike is parallel to that of the granite and schist at this point, and the " dyke " appears to be vertical or very highly inclined. Close to the river its trend changes, in common with that of the granite and schist, to 45°. It penetrates a few feet into that portion of the rock which is partly submerged in the water and then peters out, being only an inch wide here. In the same contact joint, on the eastern side of the stream, is a thin quartz vein 2 to 3 inches wide, which is traceable up the steep eastern bank of the stream. This " dyke " is therefore observable for about a hundred yards.

On the western side of the road, the " dyke " projects an inch or so above the level of the surrounding rock, but close to the stream its surface is flush with, or lower than, that of the granite and schist. It is jointed transversely to the direction of strike and, in places, gaps of an inch or two appear where small blocks have dropped down into the fissure which the dyke fills.

The second outcrop is about 1·3 miles north-west of the first. It is indicated only by the disposition of large blocks on either bank of a small tributary of the Himwa, and in the bed of the stream itself. Its trend here is 55° and it occurs at a point where, for some reason at present obscure, there is a marked local change in the direction of schistosity of the granite from 315° to 55°. Judging by the average diameter of the blocks, this " dyke " must have a width of 2 to 3 feet and the line of boulders extends for slightly less than a quarter of a mile (B, Text-fig. 1).

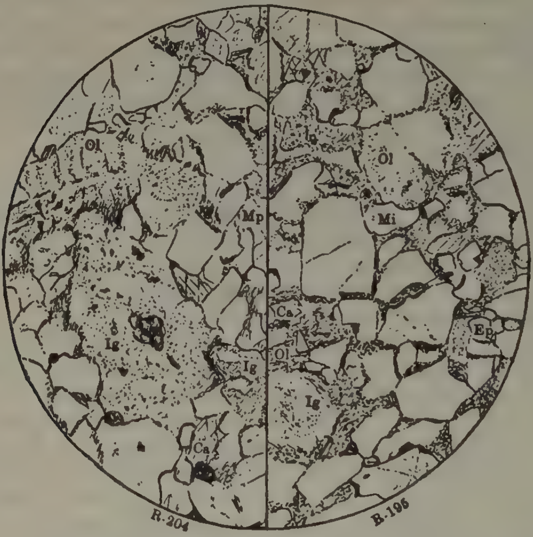
A third specimen of indurated sandstone, presumed to have come from a similar source, was found on the Fufu scarp 25 miles north-east of the Himwa falls. This specimen was broken from a boulder lying on the face of the scarp and no other outcrops were found. This portion of the scarp was investigated during the rainy season, and the scarp slopes were covered with thickly matted undergrowth which probably served to conceal the outcrop of a " dyke " such as this may have been.

3. PETROGRAPHY.

The clastic nature of these rocks is clearly displayed in the thin sections (Text-figs. 2 and 3) from specimens R-195, 204, and 148, in the collection of the Tanganyika Territory Geological Survey.

In the hand-specimens they are all reddish-brown, fine-grained, hard, and compact rocks. R-148 (Text-fig. 3) has a vitreous appearance. Small pebbles of foreign rock material including granite and chloritic schist can be clearly observed with the naked eye.

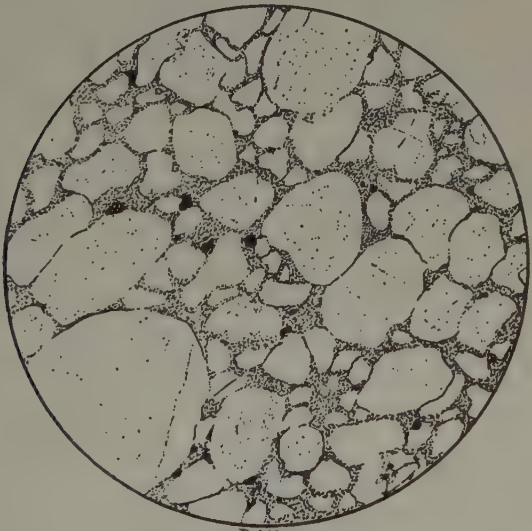
Microscopic examination of the rocks from "dykes" A and B prove that the chief constituents are angular to sub-rounded grains of quartz, microcline, and oligoclase set in a fine matrix which is essentially ferruginous but also consists partly of calcite. Many of the quartz grains exhibit undulose extinction, fracturing, and recementation. The twin lamellae of some grains of plagioclase are also bent and in some places microfaulted. Other less common mineral constituents are microcline-microperthite, micropegmatite, scattered flakes of chlorite, muscovite, and small grains of epidote, zoisite, sphene, and magnetite. There is little doubt that the source of most of these minerals is to be found in the granitic rocks of the immediate neighbourhood. The calcite may have been deposited from solution in the water which washed the sand grains into the fissure. The iron of the cement is partly limonite and partly haematite and the reddish-brown colour of the rocks is probably due to the preponderance of iron in the cement.



Text-fig. 2.—"Sandstone Dyke." Mi, microcline; Mp, microperthite; Ol, oligoclase; Ca, calcite; Ep, epidote; Ig, igneous rock fragments. Clear areas are quartz grains.

Equally conspicuous in thin section, as in the hand specimen, are the fragments of extraneous rock material, most of which are granitic, but some of which are undoubtedly pebbles of the chloritic schist which outcrops on the south-west side of the " dyke ". Several fragments of mylonized granite occur and in a sample from the second " dyke " (B, Text-fig. 1) pebbles of two distinct porphyritic rocks have been noted. Most of the foreign rock pebbles are rounded but some have a more irregular shape.

The grains of all these specimens show little evidence of sorting. In those from " dykes " A and B, the grain size varies from 0·02 to 1·5 mm. in diameter. The sub-rounded grains seem to be those with an average diameter of 0·7 mm. The constituent grains of the rock of both these " dykes " are water-worn rather than wind-blown.



TEXT-FIG. 3.—" Sandstone Dyke." Wind-worn quartz grains in cement of silica, iron, and a little calcite.

The features exhibited by R-148 (Text-fig. 3) are rather different. More than 80 per cent of the rock consists of quartz grains which are predominantly rounded to sub-rounded. There are no markedly angular fragments. The largest grains, with a diameter of 0·45 to 0·9 mm., are well-rounded. The cementing material is somewhat opaque but is probably largely silica and iron ore, while calcite is again prominent.

Foreign rock inclusions occur, but are less common than in the two rocks previously described. In this specimen they are quartzitic or quartzo-felspathic, though generally speaking felspars are only of rare occurrence. Only one detached felspar grain has been noted in the whole thin section.

This rock, in contrast to the others, appears to have arisen from the consolidation of wind-borne sand, though if it also is a fragment of a " dyke " similar to A or B, circulating water has very likely played a part in its formation.

4. Mode of Origin.

The method by which these " dykes " have formed is rather in doubt. In view of the nature of the bed-rock in these localities, it is unlikely that the material was forced into a fissure from below, though Chamberlin and Salisbury [1] have postulated such an origin for the sandstone dykes of Northern California. They consider that the sand was forced up from beneath either by hydrostatic pressure or by earthquake movements. L. J. Krige [2] has described a sandstone dyke in the Old Granite of the Ermelo district of the Transvaal, which resembles those described in this paper. In size, shape, and content of grains, the rock of this dyke is comparable with the third specimen, R-148 (Text-fig. 3); in so far as it contains granitic and other inclusions it is similar to the sandstone of the " dykes " A and B. The Ermelo dyke, however, is greater in width (7 to 12 feet), and is traceable for a greater distance (more than a mile). Krige experiences some difficulty in deciding upon the origin of the dyke but considers that it may have been formed by the filling of a fissure by wind-blown sand which fell into it or was washed into it by water; or that the sand was merely blown into the fissure. He postulates, however, a strong circulation of water carrying sand in suspension, in order to explain the existence of minute veins of the same rock as the dyke, some of them only 1 mm. in width. Krige also maintains that the fresh granite inclusions in the dyke rock can be explained only on the assumption that the dyke filled-in rapidly soon after the fissure was formed, and that this could have happened only if the sand entered from above almost as quickly as the fissure opened.

A similar mode of formation for sandstone dykes has been advanced by Jenkins,[3] and two *dolomite* dykes in the Clear Fork formation near Truscott, Texas, have been described by Kramer [4] who hypothesizes an analogous origin, though, in the latter instance, Kramer points out that dolomite dykes are apparently rare because their formation depends upon the coincidence of three conditions, viz. :—(1) the formation of cracks, and (2) the encroachment of the sea upon land containing cracks, while (3) dolomite grains are being swept along the sea floor.

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[1] Chamberlin, T. C., and Salisbury, R. D., *Geology*, London, 1905, p. 490.

[2] Krige, L. J., " An Interesting Sandstone Dyke in the Old Granite of the Ermelo District," *Trans. Geol. Soc. South Africa*, xxxii, 1929, 1930, p. 61.

[3] Jenkins, O. P., " Sandstone Dikes as Conduits for Oil Migration through Shales," *Bull. Amer. Assoc. Petrol. Geol.*, xiv, 1930, p. 421.

[4] Kramer, W., " Dolomite Dikes in the Texas Permian," *Journ. Geol.*, xlii, 1934, p. 193.

5. AGE OF THE " DYKES ".

No absolute determination of the age of these " dykes " is possible. Nothing whatever can be said of the third specimen (R-148) in this respect since its source was completely obscured. The first two are obviously in granite for, although the " dyke " A is in juxtaposition to chloritic schist on its south-west side, this schist forms a band which, while it is continuous for a considerable distance along the Fufu scarp, is of the nature of an infold in the granite.

Partly uralitized dolerites intrude the granite a short distance south-west of the Himwa falls, but have not been observed to cut the sandstone " dyke " there. In view of the very short observed length of this " dyke ", however, little importance can be attached to this fact.

Perhaps the most significant observation is that the " dyke " A, although occurring in what must be the fault zone of the Fufu scarp, shows no signs of having been disturbed by movement after its consolidation. The fractured and microfaulted feldspars, noted in thin sections, occur most abundantly in the second outcrop B, and these features are exactly similar to those exhibited by the sheared and mylonized granite in other places along the Fufu scarp. They undoubtedly represent the impress of forces which were exerted long prior to the initiation of the fault scarp. The most apparent hypothesis seems to be that the " dyke " rock fills a fissure that may have originated during the faulting. The strike of the fissure and the " dyke " itself in the case of A, and of the line of sandstone boulders at B, is parallel to the alignment of the scarp. If then, by analogy with the Ermelo occurrence, we accept the premise that these " dykes " must have filled in with sand from above soon after the fissures were formed, their formation must be contemporary with, or very little later than, the Fufu fault which is probably of Late Tertiary or Early Quaternary age.

The writer desires to record his indebtedness to the Honourable the Director of the Department of Lands and Mines, Tanganyika Territory, for permission to publish the above.

CORRESPONDENCE.

AUGITE-BIOTITE-DIORITE OF THE NEWRY COMPLEX.

SIR,—In letters which appeared in the June number of the GEOLOGICAL MAGAZINE, Professor Shand and Dr. Wells both question the meaning of my statement that augite-biotite-diorite is certainly not diorite. My meaning is exactly paralleled in Dr. Wells's own letter with reference to the same rock. Dr. Wells writes, "The rock differs from normal (calc-alkaline) gabbro in two respects: a high content of biotite, and the more strongly sodic character of the plagioclase . . . I suggest that 'hybrid sodi-potassic gabbro' is the correct name." Presumably, therefore, Dr. Wells distinguishes between normal (calc-alkali) gabbro and sodi-potassic gabbro. Similarly the terms diorite (calc-alkali) and augite-biotite-diorite (in this case alkali-rich) are not synonymous. I did not say that augite-biotite-diorite has no essentials in common with diorite, as Dr. Wells seems to imagine, for I wrote "Mineralogically, it [the rock in question] is accurately described as augite-biotite-diorite, since in addition to augite and biotite the essential minerals are andesine and hornblende."

This discussion began when Professor Bailey wrote of the rocks that they "seem perfectly normal gabbro-diorites" (GEOL. MAG., 73, p. 268, 1936). Professor Shand agrees with this opinion, whereas Dr. Wells finds that, according to a classification for which he has preference, gabbro-diorite is as yet only a mathematical fiction.

Personally I am quite indifferent as to what the rock is called, provided it is realized that it is not a normal calc-alkali type, e.g. a member of a normal gabbro-diorite-granite series, for this has a petrogenetic significance. I have already suggested biotite-essexite-gabbro as an alternative name, and in my previous letter (GEOL. MAG., 73, p. 560, 1936) I wrote, "The Slievegarron rocks under discussion do not differ from gabbro in the direction of diorite, but in the direction of alkali-rich gabbro." Dr. Wells is obviously in agreement with me on this essential point since he wishes to term the rock "sodi-potassic gabbro".

Much could be written in reply to the letters of Professor Shand and Dr. Wells. A comparison, for example, between Dr. Wells's statements in the two lines at the top of p. 288 and in his closing sentence would provide an amusing topic. There is, however, no value in carrying this discussion farther. I heartily agree with Professor Shand that "it is futile to quarrel about the application of rock names until we are agreed about the meaning of these names". I therefore propose to end the discussion by re-naming the rock *garronite*, from the hill—Slievegarron—on which it is typically developed. An adequate description of garronite, under the now abandoned term "augite-biotite-diorite", will be found in the *Quart. Journ. Geol. Soc.*, xc, 1934, 609–611, and a further discussion appears in the Geol. Mag., LXXIII, 1936, 560–2. The fact that a complete description of the rock exists should have made this prolonged discussion, as to the meaning of a name, unnecessary.

Doris L. Reynolds.

The University,
Durham.
5th June, 1937.

A PLEISTOCENE STRAND LINE IN THE VALE OF YORK.

Sir,—Mr. Wilfrid Edwards has recently described "A Pleistocene Strand Line in the Vale of York" (*Proc. Yorks. Geol. Soc.*, xxiii, 103), which he believes to be of pre-Hessle age. A part of his paper is, however, devoted to a consideration of the terraces of the Rivers Aire and Calder, from which the conclusion is drawn that the Lower (or 10 ft.) Terrace "fans out into the surface of the great mass of clays, silts, and sands which fill the Vale of York up to about 25 feet O.D."; and that the Higher (or 20 ft.) Terrace is to be correlated with the strand line and the Leeds *Hippotamus* deposit. This may lead to serious confusion if allowed to pass unnoticed.

Mr. Edwards has himself observed that: "There is indeed a marked discrepancy in level at Ferrybridge, where the beach is perched on the hilltop at 80 to 100 feet O.D., above certain patches of sand at about 50 feet O.D., which appear to be of Higher Terrace age." One might have supposed this spectacle of a river terrace some 40 feet below its presumed base-level would have caused Mr. Edwards to reconsider his hypothesis and look elsewhere for a less ambiguous example of a 20 ft. terrace. Terraces at this height fan out into the sands and silts which fill the Vale of York up to about 50 feet O.D.; they do not end on the 100 ft. level of the strand line.

In regarding the Leeds *Hippotamus* deposit as indicating an interglacial period, Mr. Edwards has arrived at a conclusion which I also reached, a couple of years ago (*Glacial Geology of Holderness and the Vale of York*, 88). On the other hand, the 20 ft. terrace is of late Hessle age.

Sidney Melmore.

York.
14th July, 1937.

A GLACIAL TRACK IN THE PEAK DISTRICT OF DERBYSHIRE versus THE POTLUCK SILL

Sir,—In the Geological Magazine for February, 1935, on page 96, is a letter from Mr. Philip Jessop, in which he says that the boulders of dolerite and the outcrop of lava "led Bemrose (*Q.J.G.S.*, 1907, 241) to infer the existence of an intrusive sill at this place. Detailed examination shows, however, that the boulders are not in situ".

Mr. Jessop postulates that the boulders have been transferred to their present locality by ice.

I have lately made several visits to Potluck. During the last year or two, a number of trial holes and several bore-holes have been made in at least three fields. The holes made near to where the boulders are on the ground, prove that the rock is in situ. I have examined thin slices made from three specimens taken from two of the bore-holes. One of them was drilled to a depth of 115 ft., and another to 70 ft., without getting through the intrusive rock. Two specimens from the first hole at depths of 106 ft. and 115 ft. respectively, consist of ophitic olivine-dolerite. From the second hole the specimen from a depth of 70 ft. is an olivine-dolerite with granular augite. They are very similar to the rocks I collected more than thirty years ago, but the olivine is in a much fresher condition. The bore-holes are about 150 yards from Black Hillock shaft.

We therefore have proof that here the sill is at least 115 ft. thick. These facts fully justify my having mapped this rock as a sill.

H. H. Bemrose.

218 Osmaston Road,
Derby.
20th July, 1937.

GEOLOGY OF ECUADOR.

Sir,—I have read with much interest Dr. George Sheppard's recent book *The Geology of South-Western Ecuador*, and, in so far as many of the results originally appeared in the pages of this Magazine, the following remarks may prove of interest to your readers. During several months work in South-Western Ecuador the writer had occasion to make preliminary reports (in note form) on specimens, etc., collected in the area described by Dr. Sheppard. A number of these observations have been included in the book (see pp. 72–74, 136–138) and it is felt that in order that due allowance shall be made for possible inaccuracies, attention should be called to the fact that these remarks were not prepared for publication, and indeed their inclusion came as somewhat of a surprise to the writer.

The palaeontological identifications were made without specialized knowledge of Tertiary mollusca and without the advantage of literature other than the standard textbooks on palaeontology. As an example may be quoted the reference to the echinoid cf. *Coelopleurus* sp. (see Sheppard, p. 137) which the writer later found in the Quaternary and living, and identified as *Arbacia incisa* (A. Agassiz) with the help of Mr. A. G. Brighton (see Barker, GEOL. MAG., 1933, LXX, p. 89). The references to sedimentation contained on pages 72–4 contain ideas which have since been modified to some extent by the writer, and were based on a very superficial knowledge of Ecuadorian geology, and for this reason may be open to criticism.

The fauna of the Tablazos was treated in a brief note in 1933 (R. W. Barker, GEOL. MAG, LXX, 84–90), to which no reference is made by Dr. Sheppard, and the species referred to as *Bulimus* sp. (p. 146) was identified as *Porphyrobaphe iostoma* (Sowerby), a species still common in the Colonche area. The echinoid referred to as *Mellita* was identified (with the help of Mr. A. G. Brighton) as *Encope micropora* L. Agassiz and considerable changes made in earlier identifications (in MS.) of Tablazo molluscan species.

Additional points, perhaps worthy of mention, are firstly the absence of any reference in the stratigraphy to the beds exposed at San Pedro (see Barker, GEOL. MAG., 1932, LXIX, 277–281), and secondly the discrepancy between the correlation given by Sheppard (p. 105) and by Vaughan (pp. 154, 157). As a result of the first, Dr. Vaughan concludes that beds of Middle and Upper Oligocene and Lower Miocene are present at San Pedro (see p. 158), whereas only a single faunal assemblage exists, the three species, *Nephrolepidina* sp. cf. *verbeeki* Newton and Holland, *Miogypsina panamensis* (Cushman), and *Miogypsina cushmani* Vaughan occurring in association at a single horizon. Vaughan also refers to the absence of the San Pedro beds from Dr. Sheppard's section.

With respect to the second point, on page 105 Sheppard refers to the Guayaquil Limestone as probably Upper Eocene (on evidence published by Vaughan in 1930), ignoring evidence given by the writer in 1932 (Barker, GEOL. MAG., LXIX, 302–303) and by Vaughan on p. 157 of Sheppard's book, which gives a "Lower or Middle Eocene, more probably Middle Eocene" age to the beds. As a result Sheppard is in favour of correlating the Guayaquil Limestone with the Upper Eocene Seca Shales, whereas Vaughan suggests correlation (on much more reliable evidence) with the Middle Grits (Lower or Middle Eocene, probably the latter). The writer is not in entire agreement with Dr. Vaughan in respect to the identification of the species of *Discocyclina* from the Guayaquil Limestone, but as this requires further research it must be deferred to a later date. No reference is made in the correlation to a paper by Todd and the writer (GEOL. MAG., 1932, LXIX, 529–543) in which a succession is given for the Peruvian Tertiary, with information regarding the distribution of larger foraminifera, which, it is felt, might have proved of value in connection with the later work of Dr. Vaughan in comparing the Ecuadorian section with that exposed in North-Western Peru. It is to be hoped that at some future date material may be available for the detailed correlation of this part of the world by means of smaller and larger foraminifera, but until this is possible the lithological studies of Dr. Bosworth and Dr. Sheppard will continue to be the standard works of reference.

R. Wright Barker.

Tampico, Mexico.
27th July, 1937.

SPRING PITS AND SANDSTONE PIPES.

Sir,—The recent account by Dr. R. W. Pocock (*Abstract Proc. Geol. Soc.*, 1937, p. 126) is of interest to me because these Cambrian pits remind me of the Sandstone Pipes in Carboniferous Limestone, described in the *Anglesey Memoir*, pp. 612–16 (also 631–2, 635–6), and shown in plates xxxviii, xxxix. The Carboniferous pipes, however, attain to considerably greater dimensions.

They have been found on five horizons, from the base of D_2 to nearly the summit of D_2b, a thickness of some 700 feet. But they resemble the Cambrian pits in that, on none of these horizons are they likely to have been far from a coast.

On pp. 615–16 I discussed their probable causes, favouring (though with misgivings) the seismic theory of Professor Hobbs. The idea of such pits having been drilled by water from below is common to his suggestion and to that of Dr. Pocock. The new evidence seems to postulate only ordinary springs, so perhaps, in view of it, we can dispense with earthquakes. Yet the size of the Carboniferous pipes seems to require uncommon vigour in the springs that drilled them out.

Edward Greenly.

Bangor.
July, 1937.

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ORIGINAL ARTICLES.

The Classification of the Ordovician Rocks.

By G. L. Elles, Reader in Geology in University of Cambridge.

THE classification of the British Ordovician Rocks has gone through many phases of instability in the past, and at the present time seems to be passing through another such phase. There are probably many causes contributing to this state of things, two of which seem to be fundamental; the first, the different facies of development exhibited in different districts by the formations making up the system; the second, the varied elements entering into the composition of the shallow water faunas *apart* from the considerations of facies; these would seem to be governed largely by possibilities of migration into the British region of the Lower Palaeozoic geosyncline from different directions, i.e. from America, from Northern Europe, and from Central Europe, so that a different type of " shelly " fauna characterizes the north-west and south-east margins.

In recent years many facts have been brought to light bearing on the subject, and there are many old facts that have had a new light thrown upon them, so that it may serve a useful purpose if these are summarized and the subject considered afresh. Broad principles such as are necessarily involved in classifications of this kind should surely not be based upon local, or even insular, considerations, but be as international as possible. If it be urged that the classification in most general use is mainly of British origin, then the facts upon which that classification was based should be carefully and critically examined in the light of recent work.

The study of the question in these days may be approached by different ways; (*a*) *stratigraphical*, i.e. the general control of deposition by earth movements, and other physical considerations.

This includes a study of the nature, size, and importance of unconformities, how far they are widespread or merely local; changes induced by an outbreak of vulcanicity; or the significance of shifting shore lines as inducing diachronism; (*b*) *facies* of deposit, shelly, graptolitic, volcanic, etc., and the conditions controlling them, with the significance of changes in facies in vertical or lateral direction; (*c*) the reflection of these changes in the faunas, the succession of these faunas, and their degree of permanence.

In the accompanying tables a classification is given which attempts the utilization of such data as are available up to the present time. They are based upon the consideration of very many British sections known to the author, and also upon conclusions that may be drawn from work in Scandinavia where many sections have also been visited by the author. The necessity for having a standard succession for these Lower Palaeozoic Rocks in the form of a Graptolite Shale succession, to which the various "shelly" faunas may be referred, becomes evident.

Lapworth's original definition of the Ordovician System (1879, a) merely stated that it was to include the rocks from the base of the Arenig to the base of the Llandovery; later in that same year (1879, b) he gave a classification in which he divided the System into three divisions:—

Upper Division (Caradoc) .	Hirnant and Bala Series of North Wales.	Caradoc Sandstone of Shropshire.
Middle Division (Llandeilo)	Llandeilo Series of Builth and Abereiddy.	Llandeilo Flags of Meadowtown.
Lower Division (Arenig) .	(*b*) Arenig Series of St. David's.	(*b*) Arenig Rocks of Shelve.
	(*a*) Upper Tremadoc.	(*a*) Stiper Stones.

The question therefore arises as to the value of these subdivisions at the present day, and the extent to which useful modifications have been made in them. It is not customary now to include the Upper Tremadoc in any *British* classification of the Ordovician System, and Lapworth was mistaken in referring the Stiperstone Quartzite to that horizon; whether, however, British geologists are wise in drawing the base line of the System at the base of the Arenig is another matter, which has been recently discussed elsewhere (Elles, 1923), and will therefore not be further considered here. It will be remembered that the English Lake District alone in Britain shows the development of the zone of *Dichograptus*.

Lapworth divided the Arenig into three subdivisions on the basis of its graptolite faunas, recognizing what would now be regarded as—

(1) Upper Arenig with the *Didymograptus bifidus* fauna,
(2) Middle Arenig with the *D. hirundo* fauna,
(3) Lower Arenig with the *D. extensus* fauna.

Much confusion exists concerning the nature and value of the Llandeilo Formation which, in 1875, had been divided by Hicks into three divisions, though subsequent work has shown that the uppermost of these is really due to repetition by overthrusting of the lower beds (Jones, 1933); there remain, therefore, two divisions for consideration, a lower division with *Didymogr. murchisoni* as the characteristic fossil, and the higher in which the dominating fossils are *Ogygia* (*Ogyginus*) *corndensis* and/or *Ogygia* (*Ogygiocaris*) *buchi*. Recent work tends to show that these faunas may mingle. It has been stated[1] that "the Llandeilo Formation as originally described by Murchison in his Silurian System (1839) was evidently intended to include only the typical Calcareous Flags and Limestone of Llandeilo". There is a strange oversight here, for the description in the Silurian System was *not* the *original* description of the formation which had been made much earlier (Murchison, 1833), when the formation was described as the BUILTH and LLANDEILO FLAGS, and noted as occurring at "Rorington near Shelve, Llandrindod and Wellfield near Builth, and from Tan yr Alt to Llandeilo, Carmarthen". That Murchison continued to believe in the importance of the Llandeilo at Builth is obvious from his references to the formation in the later editions of Siluria, where he notes the importance of it, and states that most of the best fossils characteristic of the formation come from that area. He especially notes the occurrence of *Didymograptus murchisoni* from the Llandrindod Hills (figured in *Silurian System*) as one of the characteristic fossils of these rocks.

This seems to negative another statement that has been made that Murchison did not include the zone of *D. murchisoni* in the formation (Jones, 1933). It is particularly unfortunate that this Builth-Llandrindod development has been ignored or overlooked by many later workers, for in that district there is an intercalation of the graptolite and shelly successions from the zone of *D. murchisoni up to and including the zone of Nemagraptus gracilis*. This is clearly indicated in the valuable collection of fossils from many different localities in this region made many years ago by Miss C. Chamberlain, of Newnham College, Cambridge, and the University of Birmingham. These have been lent to me by Professor Wills, and they supplement my own work considerably. The graptolites characteristic of this last zone, including numerous specimens of *N. gracilis* itself, not only occur intercalated in the more shaley beds amongst the flags, at Gwern-y-fed-fach, near Builth, and Llanfawr, Llandrindod, but occur on the *same slabs* with a rich fauna including *Ogygia* (*Ogygiocaris*) *buchi*, *Barrandia radians*, *Trinucleus fimbriatus*, *Ampyx nudus*, and *Calymene duplicata*. There can be no doubt of their contemporaneity. These trilobites have always been considered typical Llandeilo forms, and were so considered by Murchison. The general aspect of the fauna has obvious points of similarity with that of Llandeilo. This evidence at Builth was known to Lapworth when he finally definitely referred the Glenkiln shales of South Scotland to the Llandeilo, and it would seem to challenge the reference of the *Nemagraptus gracilis* beds to the Caradocian as has been done by the Officers of the English Geological Survey for some years.

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[1] The Country around Carmarthen, *Mem. Geol. Surv.*, 1909.

In the light of recent work, the value of Hick's term Llanvirn, proposed by him in 1866 for the top beds of the Arenig (zone of *D. bifidus*) and the lower division of the Llandeilo (zone of *D. murchisoni*), is doubtful. It was made on the basis of a trilobitic fauna which included *Illaenus*, *Illaenopsis*, *Barrandia*, *Placoparia*, and *Acidaspis* for the beds at Llanvirn. This fauna is associated with the graptolite fauna of the zone of *D. bifidus*, but is not particularly applicable to the horizon with which the *D. murchisoni* beds are associated, where the *Ogygia* fauna (*Ogyginus corndensis* and *Ogygiocaris buchi*) is more striking and characteristic, both in South Wales (Abereiddy Bay) and the Borderland (Whittard, 1931).

Marr, writing in 1905, considered this subdivision unnecessary; if it be retained it would seem as if it should be used only for the graptolitic facies to unite beds containing tuning-fork graptolites as *dominant forms*, though the tuning-fork graptolites, as has been shown elsewhere, come in far earlier in some abundance, and there has already been some misapprehension on that account.

In the Welsh Borderland area, the stratigraphy indicates that the migration of the shore line from the western to the eastern side of the Longmynd had been effected by the time the Harnage Shales were laid down, and it seems that all the grits towards the eastern side have been referred to the Hoar Edge Grit though one of these has yielded *Nemagr. gracilis* (Pocock and Whitehead, 1935), and must be very near the horizon of the Spy Wood Grit of the western development, and the shales above at a lower horizon than the shales above the Grit of Hoar Edge. The Hoar Edge Grit of Hoar Edge is the base of the Caradocian (Caradoc Sandstone), and at several places along its main outcrop the shales immediately above (Harnage Shale) have yielded graptolites distinctive of the zone of *D. clingani* (*D. clingani*, *Orthogr. truncatus*, *Cl. caudatus*, *Cl. bicornis*). These grits and shales used to be well exposed along the roads running East and South-East from Hope Bowdler.

These facts suggest that the Spy Wood-Hoar Edge Grit is very probably a diachronic grit, and that in places, including some localities in the northern part of the eastern development, it is overlain by shales belonging to the zone of *Cl. peltifer* and *Mesogr. multidens*, whilst along the Hoar Edge scarp it is directly overlain by shales belonging to the higher zone of *D. clingani*.

In South Wales the Dicranograptus Shales fall naturally into two groups of shale separated in the northern area by the locally developed Mydrim Limestone; the succession is thus :—

Mydrim Shale or Black Dicranograptus Shales.
    Truncatus Beds (*Orthogr. truncatus*).
    Vulgatus Beds (*Orthogr. vulgatus*).
    Mesograptus Beds (*Mesogr. multidens*). } Passage beds.
    Arctus Beds (*Amplexogr. arctus*). }
Mydrim Limestone *Nemagraptus gracilis* zone (upper).
Hendre Shales or Brown Dicranograptus Shales.
    Nemagraptus gracilis zone (lower).

The fauna of the Hendre Shales, whilst yielding some graptolites which have a fairly long range in time, includes a few which are particularly characteristic of the zone of *N. gracilis*, and do not range farther down; these are *Dicellogr. sextans*, *Hallogr. mucronatus*, and *H. bimucronatus*. The *Nemagraptus gracilis* beds, in addition to numerous *Nemagrapti* practically confined to the zone, together with abundant *Dicellogr. sextans*, *Dicranogr. brevicaulis*, *Cl. bicornis* (type a), *Cl. scharenbergi*, and *Amplexogr. perexcavatus*, yield others which are of commoner occurrence at higher horizons, such as *Dicranogr. rectus*, *D. ziczac*, *D. nicholsoni*, and *Orthogr. acutus*. The forms occurring in the Arctus Beds and *Mesograptus multidens* Beds are listed below; here, the two horizons have much in common but the relative abundance is often different. In the Vulgatus Beds above, *Dicranogr. clingani* makes its appearance, but is not common and the horizon is characterized by an abundance of *Orthograpti*, rather than *Mesograpti* or *Amplexograpti*, the distinctive feature of this horizon wherever it occurs, *Orthogr. calcaratus* and *vulgatus* come in in abundance, whilst *Orthogr. truncatus*, together with *Cl. caudatus*, are common and easily recognized fossils in the higher beds termed the Truncatus beds.

The facts appear to indicate that the Arctus beds and Mesograptus Bed really contain a passage fauna. It was the fauna of the beds now grouped as the zone of *Cl. peltifer* and *Mesogr. multidens*, that led Lapworth to regard them as Llandeilo-Bala; they were not at that time separated from those of the zone of *N. gracilis*, which further work has shown to contain a distinctive fauna in the abundant *Nemagrapti*. Lapworth, however, did separate off the horizon of *Cl. wilsoni* on account of the peculiar and easily recognizable features of that fossil, though modern work would indicate that the fauna of this horizon is closely connected with that of the *Cl. peltifer* horizon below. Hence in South Scotland the zone of *Cl. peltifer* and *Cl. wilsoni* are really passage zones between the Glenkiln and Hartfell faunas.

In South Scotland, the unconformity north of the Stinchar River is of very local importance; on the south side of the river, and elsewhere in the Northern and Central Belts, there are mudstones and cherts conformably overlying the Volcanic Series (of Ballantrae) developed to a considerable thickness, and as black shale bands come into these, the series passes into the characteristic Glenkiln

Shales, everything pointing to continuous sedimentation from Arenig time (Peach and Horne, 1899). If there be any more widespread suggestion of earth movement it lies at the horizon of the Benan-Glen App Conglomerates *above the horizon of the zone of Nemagraptus gracilis*, but there is no evidence of this being more than a local effect.

	Zone of *N. gracilis*	*Amplexogr. arctus* Beds	*Mesogr. multidens* Beds	*Orthogr. vulgatus* Beds	Zone of *D. clingani*
Nemag. gracilis .	+				
v. remotus	+				
nitidulus .	+				
Leptog. grandis .	+				
latus .	+				
validus .	+	+	+*r*		
Hallog. mucronatus	+	+			
bimucronatus	+	+	+		
Climacog. caudatus					+
bicornis (*a*) .	+	+			
bicornis (*b*) .			+	+	+
peltifer . .	+*r*	+*c*	+*r*		
scharenbergi .	+*c*	+*c*	+*c*	+	
Dicranog. brevicaulis	+	+			
clingani . .				+	+
nicholsoni .	+	+	+	+	+
rectus . .	+	+	+*c*	+*r*	
ziczac . .	*r*	+	+		
Amplexog. arctus .	+*r*	+*c*	+	+	
perexcavatus .	+	+*c*	+*c*	+	+
Mesog. multidens .		+*r*	+*c*	+	
v. compactus .		+	+	+	
Orthog. acutus .	+*r*	+	+	+	
basilicus . .				+	+
vulgatus . .			+	+	+
calcaratus .				+	+
truncatus .					+
intermedius .			+	+	
Dicellog. sextans .	+	+	+		

Range of Graptolites belonging to Zone of *Cl. peltifer* and *Mesogr. multidens.*

Leptograptus validus+.
Dicellogr. divaricatus var. *rigidus*+ and var. *salopiensis*+, *D. patulosus* (c).
D. sextans+.
Dicranogr. brevicaulis+, *nicholsoni*+°, *rectus*+°, *tardiusculus*, *ziczac*+.
Climacogr. antiquus+, *bicornis*+°, *scharenbergi*+°.
Amplexogr. perexcavatus+°.
Mesogr. multidens° and var. *compactus*°.
Hallograptus mucronatus+ and *bimucronatus*+(c).
Orthogr. acutus, vulgatus, intermedius.

+ range down
° „ up.

From the purely palaeontological standpoint, it may be well to note that though the zone of *Nemagraptus gracilis* contains many graptolites that are confined to the horizon, the elements composing it are essentially those characteristic of the Second or Leptograptid Fauna (Elles, 1922), *Nemagrapti*, *Leptograpti*, *Dicellograpti*, and *Climacograpti*, with simple type of Leptograptus cell, accompanied by some *Glyptograpti* (scandent *Leptograpti*), *Amplexograpti*, and *Mesograpti*, i.e. a typical Llandeilo fauna. It is misleading in the extreme to state that the Llandeilo is characterized by *Diplograpti*, the great " burst " of *Diplograpti* (*Orthograpti*) commences in the transition beds and dominates the whole of the Hartfell facies of the Caradocian.

The last addition to the Ordovician classification was Marr's term Ashgillian for the rocks to which the term Upper Bala had been applied (Marr, 1913, 1916). As finally defined by him, this division consists of two " shelly " zones (see table III), of which the lower is the most commonly developed, the presence of the other being apparently determined by the existence and degree of unconformity of the Valentian rocks above. Both horizons are the equivalent of the graptolite zone of *Dicellograptus anceps*. In places where the well-known Barren Mudstones are developed, the pathological (dwarfed) horizon of the zone of *Dicellograptus complanatus* may occur, but when the succession is more normal a high development of the zone of *Pleurograptus linearis* is found in which *Climacograptus styloideus* and *Orthograptus pristis s.str.* are characteristic forms (King, 1923). In Scandinavia a small form of *Dicellogr. anceps* occurs with this fauna so that in all probability it lies close below the zone of *D. anceps*. Since it is *conditional*, the zone of *D. complanatus* is not included in the table.

SCANDINAVIA.

It is to Scandinavia that British geologists turn instinctively for greater information about the Lower Palaeozoic rocks. In Sweden the beds in many places are so little disturbed that no doubt can possibly arise concerning the succession ; three facies are developed, (*a*) a shore facies with sandstones and conglomerates containing large brachiopods, (*b*) a shallow water facies often largely limestones characterized by a trilobite-brachiopod-cephalopod fauna, and (*c*) an off-shore facies of shales and mudstones characterized mainly by graptolites ; the relation of these beds is often particularly interesting and instructive in regard to the matter under discussion. These relations are shown in the accompanying table II.

In Scandinavia the zone of *Dictyonema flabelliforme* is taken as the base of the Ordovician System since it has been found that in many places the Ceratopyge Limestone merges imperceptibly into the *planilimbata* Limestone of the Orthoceras Limestone. The Orthoceras Limestone is differently developed in different districts ;

TABLE I.—THE CLASSIFICATION OF THE ORDOVICIAN ROCKS.

		WALES AND THE WELSH BORDERLAND.[1]		SCOTLAND.[1]	
		Shelly Faunal Succession	*Graptolitic Succession*	*Graptolite Succession*	*Mixed Shelly and Graptolite Succession*
ASHGILLIAN		*Phacops mucronatus* and *Hebertella sagittifera* *Phillipsinella parabola* and *Trinucleus bucklandi*	Zone of *Dicellograptus anceps*	Zone of *Dicellograptus anceps*	*Drummuck Mudstones* with *Phillipsinella parabola*, *Trin. bucklandi*, and graptolites of Zone of *D. anceps*
CARADOCIAN	*C.* (*Flexicalymene*) *planimarginata*	*Chasmops* and *Pterygometopus jukesi*, *Nicolella actoniae*	Zone of *Pleurograptus linearis*	Zone of *Pleurograptus linearis*	*Whitehouse Beds* with many *Trinucleus*, *Stygina latifrons*, *Encr. multisegmentatus* and graptolites of Zone of *P. linearis*
		Asaphus powisi and *Heterorthis alternata*	Zone of *Dicranograptus clingani*	Zone of *Dicranograptus clingani*	*Ardwell Flags* *U.* with graptolites of Zone of *D. clingani*
PASSAGE BEDS		*Orthis* (*Dalmanella*) *argentea*	Zone of *Mesograptus multidens.* Sub-zone of *Amplexograptus arctus*	Zone of *Cl. wilsoni* Zone of *Cl. peltifer* Zone of *Cl. peltifer*	*M.* with graptolites of Zone of *Cl. wilsoni* *L.* Knockgerran Shales with graptolites of Zone of *Cl. peltifer* *Balclatchie Beds.* Grits, conglomerates, and mudstones with rich *Remopleurides fauna*

LLANDEILIAN	*Ogyginus corndensis*, *Ogygiocaris buchi*, *Siphonotreta micula*	Zone of *Nemagraptus gracilis*	Mudstones and Grits Zone of *Nemagraptus gracilis*	*Benan Conglomerate* Shales with graptolite fauna of Zone of *N. gracilis*
	Ditto.	Zone of *Glyptograptus teretiusculus*	Radiolarian Cherts, Mudstones and Volcanic Tuffs	*Stinchar Limestone*, with rich *Illaenus* fauna *Kirkland Sandstone* *Kirkland Conglomerate*
Llanvirn of Hicks	Ditto.	Zone of *Didymograptus murchisoni*		
	Cyclopyge and *Placoparia*, *Orthis proava*	Zone of *Didymograptus bifidus*	Mudstones and Cherts (radiolarian)	Gap
ARENIGIAN	*O.* (*Niobella*) *selwyni* and *Orthis proava*	Zone of *Didymograptus hirundo*	Shales	Radiolarian Chert and Shales
	Ditto.	Zone of *Didymograptus extensus*	Volcanic Series (Ballantrae) with intercalated Shales and Cherts	Volcanic Series (Ballantrae) with intercalated shale and chert and extensiform graptolites

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[1] After Elles (1922), King (1923), Lapworth (1879, 1882), Marr (1913, 1916), Whittard (1931).

TABLE II.—THE CLASSIFICATION OF THE ORDOVICIAN ROCKS OF SCANDINAVIA.

NORWAY.	SWEDEN.		
(Oslo) (mixed)	Västergötland, Dalarne Öland (Trilobite-Brachiopod Facies)	Andersön, Jämtland (mixed)	Skåne (Graptolite facies)
	Upper Leptaena Lst. (Dalarne) Brachiopod Shale		
	Staurocephalus Shale Trinucleus Shale Lower Leptaena Lst. (Dalarne)		Upper Dicellograptus Shales Zone of *Dicellograptus anceps*
Ampyx Lst.	Chasmops Limestone Echinosphaerites Lst.	Zone of *Dicranograptus clingani*	Middle Dicellograptus Shales Zone of *Pleurograptus linearis* Zone of *Dicranograptus clingani*

Ampyx Lst.	Ancistroceras Lst. (Upper grey)	Ogygiocaris Shales: Zone of *Nemagraptus gracilis*	Lower Dicellograptus Shales Zone of *Nemagraptus gracilis*
Ogygiocaris Shales: *Climacograptus putillus* *Glossograptus hincksi* *Didymograptus geminus* *Phyllograptus*	Orthoceras Limestone: Centaurus Lst. (Illaenus) Platyurus Lst. (Upper Red) Gigas Lst. Asaphus Lst. (Lr. Grey)	Zone of *Climacograptus putillus* Orthoceras Lst.: Platyurus Lst. Gigas Lst.	Zone of *Climacograptus putillus*[1] Zone of *Glossograptus hincksi*[1] Upper Didymograptus Shales Zone of *Didymograptus geminus* Zone of *Phyllograptus* cf. *typus* Lower Didymograptus Shales (with extensiform Didymogr.) Zone of *Isograptus gibberulus* Zone of *Phyllograptus angustifolius* Zone of *Didymograptus balticus*
	Limbata Lst. (Lr. Red)		
	Planilimbata Lst.		
	Ceratopyge Lst. Shale or Obolus Conglomerate		

After Hadding (1913), Holtedahl (1909), Moberg (1911), Warburg (1925).

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[1] Yield abundant *Glyptograptus tereliusculus*.

TABLE III.—THE CLASSIFICATION OF THE ORDOVICIAN ROCKS.

	S. WALES	N. WALES	SHROPSHIRE		LAKE DISTRICT
			W.	E.	
ASHGILLIAN	Slade and Redhill Beds Sholeshook Limestone	*Phacops mucronatus* Beds *Trinucleus bucklandi* Mudstones *Phillipsinella* Beds		Trinucleus Shales	Ashgill Shales *Phacops mucronatus* Beds *Phillipsinella* Beds
CARADOCIAN	Robeston Wathen Lst. ? (local) Black Dicranograptuus Shales (Mydrim Shale) with Passage Beds	Bala Lst. (Gelligrin) Ash Allt Ddu Mudstone Ash Glyn Gower Sandstone Dicranograptus Shales (Nant Hir) Passage Beds Volcanic Series of Snowdon	Whittery Shales Whittery Volcanics Hagley Shales Hagley Volcanics Aldress Shales	Acton Scott Beds Cheney Longville Flags Chatwall Sandstone Harnage Shales Hoar Edge Grit (diachronic)	Coniston Lst. Sleddale Beds

	Mydrim Limestone (local) Brown Dicranograptus Shales (Hendre Sh.)		Volcanic		Spy Wood Grit (diachronic) Rorrington Flags		Borrowdale
LLANDEILIAN	Llandeilo Flags and Limestone Ash		Series of		Meadowtown Flags and Limestone		Volcanic
	Murchisoni Shales	Llanvirn	Arenig	Llanvirn	Betton Beds Weston Beds		Series
	Bifidus Shales		Olchfa Shales		Stapeley Volcanics Hope Shales		Skiddaw Slates
ARENIGIAN	Tetragraptus Shales with Volcanics		Filltirgerig Beds Erwent or Ogyga Lst. Henllan Ashes Llyfnant Flags Basal Grit		Mytton Flags Stiperstone Quartzite		

it may represent everything between the Ceratopyge Limestone and the Echinosphaerites Limestone, or may be partially or entirely replaced by graptolite shale. The Cephalopods, while forming a striking part of the fauna on account of their size, are accompanied by an important trilobitic fauna, in which various Asaphids are characteristic of the lower portion (lower red and lower grey), and *Illaenus* more abundant in the higher (upper red and upper grey). Other trilobites are, however, of common occurrence (Törnquist, 1884), such as *Cheirurus* and *Cyrtometopus* in the lower grey, *Pterygometopus* in the upper red and *Ogygiocaris* in the upper grey limestone. In the Upper Ogygiocaris Shales with *O. dilatata* the shaly equivalent of the upper part, in addition to the *Ogygias*, *Cheirurus*, *Remopleurides*, *Robergia*, *Ampyx*, and *Trinucleus*, are abundant forms. *This Asaphus-Ogygiocaris fauna dies out above the zone of Nemagraptus gracilis, but occurs associated with graptolite shales up to and including that horizon, just as it does in Britain.* Here also the beds below the *Dicranograptus clingani* zone have a *Mesograptus-Climacograptus* fauna, and this is also the horizon of *Orthis* (*Dalmanella*) *argentea*. *Cheirurus*, *Sphaerocoryphe*, *Cybele*, *Illaenus*, *Remopleurides*, also occur higher up in the system as characteristic fossils.

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The Age of the Jamaica Granodiorite and its Associated Rocks.

By C. A. MATLEY.

I. INTRODUCTION.

IN a paper published in 1929 on "The Basal Complex of Jamaica, with Special Reference to the Kingston District" (Matley, 1929, 440–92)[1] I gave an account of the nature and structural relationships of a complex of rocks consisting partly of plutonic rocks (granodiorite and serpentines) and partly of metamorphosed igneous and sedimentary rocks, now chiefly in the condition of amphibolites, hornblende- and chlorite-schists, quartz-sericite-schists, and marbles. The paper, which contained an important Appendix by F. Higham on the petrography, presented the results of many months' arduous work in the field, including the detailed mapping of the Kingston District, for which a good contoured map was available on the scale of 2½ inches to the mile. The geology of the area is so difficult that, in my opinion, the only way of arriving at sound conclusions is by adequate field-mapping.

The conclusions that I reached were that these plutonic and metamorphic rocks formed a Basal Complex which underlies unconformably the Upper Cretaceous and Tertiary strata of Jamaica.

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[1] For references see "Literature Cited" at the end of this paper.

The metamorphism was considered to be partly due to hydrothermal alteration by the granodiorite and partly to dynamic forces of an earlier date than the granodiorite intrusion. The granodiorite itself, although one of the younger rocks of the Complex, contributed abundant pebbles to Upper Cretaceous conglomerates and had already been uralitized at that date. The Complex was therefore pre-Cretaceous and probably pre-Mesozoic in age, and, as there was no fossil evidence to the contrary, it might even be pre-Palæozoic. The petrological evidence was in harmony with these views.

These conclusions have been challenged by Dr. C. T. Trechmann in a paper recently published in this Magazine (1936*a*, 251–267) under the title "The Basal Complex Question in Jamaica", in which he adopts the views of R. T. Hill in 1899. Trechmann's opinion is that "the large granodiorite-porphyry (*sic*) bathylith is intruded into Cretaceous and Tertiary beds as high as well up in the White Limestone (Oligocene or Lower Miocene). . . . The Serge Island marble is probably altered limestone of the Carbonaceous Shale or Richmond beds"; and he concludes: "In the writer's opinion no evidence of an old pre-Cretaceous basement has been found in Jamaica" (p. 267). There are other less important points on which he also differs.

Immediately on receipt of this paper I expressed my dissent from his opinions in a letter printed in the July number (331–3), and stated that I proposed to deal with them in a forthcoming memoir on the geology of the Kingston District. Illness has since so seriously impeded the preparation of that memoir that it will be better to follow up the controversy now.

I have to thank Dr. Trechmann for the loan of his microscope slides and of three rock specimens. They have proved very useful as they support my criticism of his statements and opinions. Dr. F. Raw, of Birmingham University, has examined the slides, and Dr. A. Heard, of Cardiff, has sliced and reported on the hand specimens. I am grateful to them for their kindness.

II. Review of Dr. Trechmann's Paper.

Trechmann's evidence and arguments will now be reviewed in so far as they are relevant to the discussion, and as far as practicable the captions used for the various sections of his paper will be adopted. Before, however, proceeding with the criticism, it may be useful to mention, for the information of geologists not acquainted with Jamaican geology, that the White Limestone which is constantly referred to in the following pages is a Tertiary limestone, estimated by Sawkins to be 2,000 feet thick, which covers more than half of Jamaica. Its age extends from Upper Eocene to Lower Miocene. It may be compared in its importance, appearance, and scenic effects, though, of course, not as regards age, with the Carboniferous

Limestone of England. It is one of the most stable rocks of the island and is exposed in hundreds of magnificent scarps and sections. If the granodiorite were, indeed, intrusive into this formation, one would expect that the advocates of intrusion would be able to produce abundant unchallengeable evidence, instead of having to rely on one or two occurrences which, at best, are disputable. The same argument applies to the Yellow Limestone (of Middle Eocene age) which underlies the White Limestone in many parts of Jamaica, but in which no one has detected a granodiorite intrusion.

General Structure (pp. 254–5).—The author says: "The large granodiorite-porphyry intrusion . . . dates from late Oligocene to Miocene times (pre-Middle Miocene or pre-Bowden beds)," and on p. 267 he speaks of it as "the large granodiorite-porphyry bathylith". Exception should, I think, be taken to the application of the rock-name "granodiorite-porphyry" to the "bathylith"—if bathylith it be—of Jamaica, because a porphyry (whether granodioritic or of any other composition) is a hypabyssal rock and cannot form a bathylith. It seems, however, from his account of the Guy's Hill area, that he means "granodiorite *cum* porphyry", as he finds both types of rock there; but he has yet to prove that the porphyries are of the same age and part of the same magma as the granodiorite. There are porphyries of more than one age in Jamaica. Some of them, including the largest and most important, are certainly much younger than the granodiorite and are recognized as of post-Basal Complex date. Much disservice has been done to the progress of Jamaican geology in the past by lumping together the igneous rocks and treating them as though they had all been injected or extruded at a single period.

Conglomerates in Jamaica (pp. 255–6).—Trechmann says of the Cretaceous Purple Conglomerate: "I have never seen any [pebbles] of the gneiss or schist in it and very few or any of granite." Except by suggesting in this sentence that granodiorite pebbles do not occur in this deposit, he does not discuss anywhere in his paper the difficulty of reconciling the presence of granodiorite pebbles in this conglomerate with his hypothesis of the Tertiary age of this plutonic rock. Surely the negative evidence of his personal experience is insufficient to dispose of this problem. In the description of the Purple Conglomerate in my 1929 paper I stated:—

"Red andesitic rocks are the chief ingredients of the conglomerates almost everywhere else, yet pebbles of the granodiorite are sparingly, but widely, distributed throughout the contents of this formation, and have been noted by me at various horizons and at many localities. They range in size from small pebbles to boulders measuring 3 feet in diameter, as at Mount Vernon, where many boulders were seen; and again abundantly south-east of Bardowie, where two boulders measured 18 × 28, and 22 × 34 inches. . . . It is clear, therefore, that the Plutonic Complex of Jamaica had been stripped of its cover and exposed to denudation in Upper Cretaceous times.

Whether the Red Andesite Group is part of the Complex or a volcanic cover of Cretaceous age is at present uncertain" (1929, 450).

I may add that Mr. Stockley, who accompanied me over part of the area, was equally convinced that the granodioritic pebbles in the Cretaceous and Eocene conglomerates afforded complete proof of the pre-Late Cretaceous age of the rock, and expressed this view in his 1925 Report (1925, 31–2). Nor is this a recent discovery, for G. P. Wall, so far back as 1863, in reporting on the Purple Conglomerates along the River Wagwater, stated that "the larger fragments also consist of a variety of igneous rocks, especially those in the vicinity, as red porphyry, felspar trap, Labrador trap, etc., and some more distant, as syenite, diorite, and more rarely granite" (Sawkins, 1869, 111).

Dr. Trechmann does not seem to have visited the localities mentioned in my paper, nor to have gone to Dallas, where I showed (1929, 450) that the floor of the Purple Conglomerate "is seen to consist of granodiorite, brought up as small elliptical domes which are covered by bouldery conglomerates, with arkose seams, made of granodioritic material". In his latest communication he again says (1936 *b*, 383): "I have never seen pebbles of the granodiorite in the Blue Mountain conglomerate," and adds, "in my opinion it is impossible definitely to identify the source of origin of any of the pebbles in that bed." As there is no doubt that such pebbles, indistinguishable in their megascopic and microscopic characters from the plutonic mass, do occur in that formation, and must have come from a Jamaican source, he can only uphold his thesis on the supposition that there are *two* granodiorites in the island with similar characteristics, one of pre-Cretaceous date, and one of Tertiary age. There is no evidence for this.

The "Metamorphosed Series" of Sawkins (pp. 256–7).—Sawkins and his associates of the official survey mapped large areas in Jamaica as "Metamorphosed series" in the sixties of last century, when the study of metamorphism was in its infancy and the microscope was not used in its investigation. The series comprised "strata of the cretaceous and conglomerate formations which have experienced a change of structure due to the intrusion of igneous rocks" (Sawkins, 1869, 47). It was therefore a metamorphic, not a stratigraphical unit, and was discarded by R. T. Hill in his revision of Sawkins's map in 1899. Although the rocks of the Basal Complex form a portion of some of these "metamorphosed" areas, much of the ground so mapped consists of quite unaltered rocks of Cretaceous and later date.

This section of Dr. Trechmann's paper has little bearing on the question of the Basal Complex. He describes, from the parish of Clarendon, some conglomerates of Cretaceous age, the pebbles of which are chiefly red andesites, and attempts to justify Sawkins in mapping them as metamorphosed rocks. He gives a puzzling account of the supposed alteration, based chiefly on the condition of the felspar crystals, and offers "three alternative explanations . . . to explain the peculiar occurrence of the metamorphosed series". This seems unnecessary, because not one of his rock-sections shows any metamorphism, the andesites being remarkably fresh and unaltered. Nine slides have been examined by Dr. Raw, the following being his reports on five of them. The remaining four are similar fresh rocks.

Slides as labelled.	*As diagnosed.*
South of Arthur's Seat.—The Cretaceous Conglomerate and Bedded Series altered to this.	Andesitic tuff. No more than the usual alteration by weathering and volcanic resorptions. Ferromagnesians are largely replaced by ore, as though metalliferous solutions have passed through.
Crooked River, near Trout Hall.—Pebble in Blue Mountain Conglomerate. "Semi-metamorphosed" Bits of matrix in the quartz-grains ?	A typical quartz-porphyry or dacite. Phenocrysts of plagioclase and quartz in a very fine microcrystalline matrix. No evidence of metamorphism.
Smithville.—Trappean Conglomerate. Pebble and matrix are changed to this.	Fresh dacite, with basaltic hornblende.
Near Smithville. — Blue Mountain Conglomerate (Upper Cretaceous) altered. Pebbles and matrix altered.	Wonderfully fresh andesite; the felspars are cracked and somewhat turbid but relatively fresh. Hornblendes are quite fresh and are probably of peculiar composition. They have the black border characteristic of lavas.
Near Spaldings.—Trappean Conglomerate (Cretaceous). Pebble and matrix of the Blue Mountain Conglomerate are altered to this.	A very fresh hornblende-andesite, containing much original magnetite. The hornblende is basaltic hornblende. The fresh plagioclases are beautifully zoned. No quartz present. A very fresh rock.

I have always recognized these conglomerates as of Cretaceous age and as post-Basal Complex rocks.

Serpentine Intrusions (p. 258).—There are some masses of serpentine (an altered peridotite) associated with the Basal Complex rocks of Jamaica. Pebbles of it, already in the condition of serpentine, have been found by Stockley (1925, 32) in conglomerates of Late-Cretaceous or Early Eocene age. This rock is thought to be of earlier date than the granodiorite intrusion and is considered by Stockley and myself to be a Basal Complex rock. Trechmann does not seem to have studied the field relations of these masses, yet, merely on the ground that he has seen two greenish dykes cutting Cretaceous rocks, he argues that the true serpentine masses "may also be of Cretaceous or later age and need not necessarily indicate a Jurassic or old Basal Complex age" (p. 258). Unfortunately, his rock-slices of these two dykes, which have been examined by Dr. Raw, are not serpentine rocks and are not related to peridotites. The "serpentinous" dyke west of Chapelton shows no serpentine in the slide and was probably originally a porphyrite, but is extensively altered and epidotized. The ferromagnesian minerals are now in the condition of chlorite and epidote, and the felspars are also epidotized to some extent. The second occurrence is a "dyke" on the Plantain Garden River, west of Bath. The slide shows that the rock is a highly vesicular andesite, with plagioclase, augite, and hornblende in a fine dark amygdaloidal matrix, the amygdales consisting of calcite. It has more the characters of a lava than of a dyke. The author's argument therefore fails completely.

The Serge Island Marble (p. 258).—The rocks in the almost inaccessible country north of Serge Island were described and their stratigraphical position discussed in my 1929 paper, and my reasons for assigning them to the Basal Complex were stated. I have shown that the granodiorite, in my opinion one of the later rocks of the Complex, is present, and as none of the metamorphic marbles elsewhere is an altered representative of the Basal Eocene limestones, I judge that the Serge Island marble, like the others, is a member of that Complex. The author adds nothing to our knowledge of these rocks, and we have only his personal opinion, founded on the "position and appearance" of the marble, that it is of later age. I do not accept his opinion.

The Granite Junction along the Wagwater River (p. 259).—Here the author adduces field evidence that at two localities in the bed of the river Wagwater the granodiorite intrudes the Cretaceous Purple Conglomerate and must be younger. As this is *prima facie* very unlikely, because the conglomerate itself contains pebbles and boulders of the granodiorite, and as his purpose is to refute the published views of Stockley and myself, one would have expected him to present his evidence in the most complete and convincing manner. It would have been satisfactory had photographs or sketches been made of these occurrences, with collections of specimens from the contacts of the igneous and sedimentary rocks, to show (*a*) that the junctions are truly intrusive and show thermal alteration of the invaded rock, (*b*) that the invading rock is indeed the granodiorite, as we know that there are igneous rocks later in age than the Purple Conglomerate which invade it elsewhere as sills and dykes, and (*c*) that the invaded rock is not one of the Red Andesites which underlie the Purple Conglomerate and may belong to the Basal Complex. The only help of this kind that the author has afforded is a slide and a hand-specimen of the granodiorite from the northern locality.

The southern of his two localities is at Golden Spring, where the Iron River enters the Wagwater. I mapped the junction here as a high-angled thrust which I had traced for some miles, and his description seems consonant with the view that masses of the granodiorite have been detached and involved with the crushed material along the thrust-plane. I put this view to Dr. Trechmann in my published letter (1936, 332) and he appears to accept it, as in his rejoinder

(1936 *b*, 382) he admits that the junction here is a thrust and that "lumps of coarse-grained granodiorite have been disengaged and mixed with crushed material".

This leaves only the northern exposure, situated 1¼ miles east of Lawrence Tavern, to be considered. It lies on the same line of thrust, and my interpretation that the junction is of this nature is supported by the specimen which Dr. Trechmann has sent me, marked "Granite at junction with Conglomerate. Gneissose tendency". Dr. A. Heard, who has kindly sliced it, reports that it has had much mechanical deformation. As he has not observed any ferromagnesian minerals in the slide he thinks it must be part of a pegmatite. A slide from this locality is said by Dr. Raw to be an aplitic variation of the granodiorite and to be shattered in parts. We may have here either a crush-breccia of conglomerate and granodiorite, or, if veins of granodiorite or pegmatite do ramify other rocks here (as the author asserts), the invaded material will probably prove to be the red and purple andesites below the conglomerate base, which are seen here and there to form a narrow strip between this thrust and the conglomerate base (Matley, 1929, 450 and pl. xxiii).

Guy's Hill Area (pp. 259–60).—The author gives a brief description of a tract of country between Linstead and Guy's Hill, apparently with the object of showing that the granite or granodiorite is intrusive into the Tertiary White Limestone on the south and into Cretaceous limestone on the north. My personal acquaintance with the area is confined to having once motored through it, along the Devil's Racecourse road on my way to Kingston, and making a few notes *en passant*, and I then realized that much of the ground here mapped by Sawkins as "granite and syenite" consisted of non-plutonic rocks (1929, 460, n.). This is confirmed by the author's account, but I should like to have more evidence for his statement that the porphyries "merge" into the granodiorite, as in nearly every case where I have found the two types in juxtaposition I have come to the conclusion that one of them was intrusive into the other.

With my very limited knowledge of the area I cannot deal with the details of the author's account, but one has only to examine his rock slices to realize what little confidence can be placed in his field descriptions. In my opinion, he has recognized thermal alteration of sediments where none exists, and regarded as altered limestones rocks which the microscope shows to be igneous. Most of his "altered limestones" are in this category, and his "hornfelses" are not hornfelses. Seventeen slides from "South of Guy's Hill" have been examined by Dr. Raw, and his reports on some of them appear on p. 502.

When his account is compared with his microscope slides it is obvious that his case for Tertiary intrusion collapses entirely. He admits that "the actual southern junction [of the igneous rocks]

Slides as labelled.	*As diagnosed.*
Cretaceous or White Limestone involved in Igneous Complex.	A felspathic porphyrite.
'*Y*' *on map.*—Altered limestone among Igneous Complex. Probably Cretaceous Limestone.	This is a porphyry, with glomeroporphyritic texture and with veins of secondary plagioclase felspar, epidote, and zoisite. The matrix is microgranular after spherulitic structure.
'*Z*' *on map.*—White Limestone becoming altered near Igneous Complex. (Two slides.)	A porphyritic igneous rock. Phenocrysts of plagioclase in microlitic and microcrystalline matrix. (A third slide with similar label shows a more obscure rock, which, however, does not suggest that it was ever a limestone.)
Near the Igneous Complex (*S. of it*).—White Limestone altered.	Relatively vitreous igneous rock, with felspar phenocrysts and a matrix of very thin felspar plates and glass. A glassy porphyrite, much altered.
White Limestone darkened and hardened, involved in Igneous Complex.	Originally perhaps highly vesicular somewhat porphyritic glassy igneous rock. No calcite. A few phenocrysts of felspar. Many veins rich in epidote. The cavities are filled with silica.
Cretaceous Limestone involved in Igneous Complex. Becoming serpentinized (?).	Originally a glassy acid lava with flow-texture, now a mosaic of crystal grains, chiefly felspar with a little epidote.
Road between Linstead and Guy's Hill, on south side of the Igneous Complex.—Hornfels. White (or Yellow) Limestone altered near igneous intrusion.	Neither a hornfels nor a limestone but a fine-grained felspathic porphyrite.
Hornfels in Igneous Complex.	A rhyolitic glass tuff, now entirely devitrified. Flow and perlitic texture. Contains much quartz and epidote in veins; some serpentine.
Hornfels in Igneous Complex.	A porphyrite with some large plagioclase phenocrysts and a matrix which is now a mosaic of felspar crystals and may be largely secondary. Much epidote and limonite.
Cretaceous Limestone involved in Igneous Complex.	A mosaic apparently of felspar as grains with elongate outline together with radial aggregations of epidote and zoisite. Contains groups of large felspars, apparently original phenocrysts. Probably originally a porphyritic igneous rock very extensively recrystallized.
Just north of Igneous Complex.—Cretaceous Limestone becoming altered.	A sandy highly fossiliferous limestone, the fossils being beautifully preserved. The sand consists partly of quartz and partly of fine-textured (including glassy) igneous rocks. No signs of alteration.

with the Tertiary limestone could not be seen ", and it now appears that the " considerable width of hard streaky and splintery hornfels, apparently altered White or Yellow limestone ", on which he seems to rely as proof, is neither a hornfels or a limestone, but an igneous rock. On the north side, where " darkened but little altered Cretaceous limestone " succeeds the igneous complex, his slide shows no evidence of contact-alteration. It is true that two slides (from a single locality on the north side of the complex) show the Cretaceous limestone in contact with a porphyritic igneous rock (not the granodiorite), but this occurrence is of little interest as intrusions into the Cretaceous beds are well known and are of post-Basal Complex age.

Hollymount and Mount Diablo (p. 260).—I have more than once examined the roadside section at Mount Rosser described by the author, and on page 460 (footnote) of my 1929 paper, I pointed out that the official surveyors were wrong in mapping the igneous rocks here as " granite and syenite " as they are non-plutonic. Their relation to the limestones is, as the author states, obscured, and I saw no definite alteration arising from their presence. I never regarded this occurrence as part of the Basal Complex, and should like some proof of the author's statement that the light coloured porphyry " merges into granitic material ", as I found no trace of any plutonic rock there.

The Lazaretto, near Port Henderson (pp. 261–2).—I have already commented (1936, 332–3) on the author's interpretation of the cliff section below the Lazaretto. He has since sent me two hand specimens and two microscope slides. Here is Dr. Raw's report on the slides :—

As labelled.	*As diagnosed.*
White Limestone blackened and altered.	Jaspery rock, intensely brecciated and impregnated with calcite and a certain amount of chlorite. Limonitized iron ore occurs extensively as strings. The rock appears to have been somewhat sheared as well as brecciated. May be an altered chert.
Dark rock among White Limestone. May be White Limestone altered ? Decomposed " Hornfels ".	Consists essentially of finely divided silica darkened with carbonaceous dust and limonitic veins and containing disseminated calcite or related carbonate and veined with calcite and quartz. Trace of chlorite (?) in the veins. No organic structure traceable. May have been originally a chert.

One of the two hand specimens is a marble and resembles in general the metamorphic marbles of the Basal Complex, except that it does not have the schistose appearance which is common in the latter. The other labelled " Rotten Hornfels " is a weathered soft green rock highly charged with white veins of calcite. I sent them to my friend, Dr. A. Heard, who cut thin slices and reported that the first was a fairly even-grained marble in which he observed only calcite, and of the second, that he was not able to get a satisfactory slide of this very small badly weathered specimen and could only describe it as a fine-grained schist, very highly calcified. It is a pity that more and better examples of the rocks below (2) of the author's text-figure are not available, as a variety of rocks seems, from his account, to be present, but it is evident that they are not metamorphic derivatives of the White Limestone. His suggestion (1936 *b*, p. 382) that the limestone has been modified in this way " by gases travelling ahead of an intrusion melting their way rapidly into the white limestone and then coming to a standstill " is a pure speculation to escape from the difficulties of his interpretation.

It is unfortunate that he could not find the hornblende-schists and amphibolites below the limestone on the road not far away, as in 1927 I was able to obtain many good specimens from the core of the limestone dome. To connect the base of the limestone there with my suggested base in Trechmann's cliff section presents no stratigraphical difficulty, and to my mind it is obvious that in this area the White Limestone lies directly on various rocks of the old Complex, which had been metamorphosed long before Tertiary times. Nor does the author's section throw any light on the age of the granodiorite, which is not present, as the alteration of these rocks is not necessarily thermal. It is probably regional.

The Rio Pedro and the Road to Harkers Hall (p. 262–3).—This area was fully dealt with on p. 445–9 of my 1929 paper. I showed that between the granite and the White Limestone there often lay a metamorphic group of " micro-granulites and hornfelses and a less altered porphyry ". The granulites around Jack Hill were " originally calcareous shales, impure clayey, and siliceous limestone, siliceous mudstones, andesitic tuffs, and probably basic lavas, all of which had suffered thermal alteration from the granodiorite. Some are brecciated, sheared, and foliated, and the microscope gives evidence that dynamic agencies had affected some of them before the granodiorite was injected " (446). At and around Kerry Castle the altered rocks consist chiefly of " pyroxene-granulites and amphibolites, which originally were intermediate or basic rocks, probably lavas ; but altered sediments are also present which at some time have been subjected to dynamic action " (447). It should be noted that no member of the metamorphic suite was originally a " White Limestone ".

The base of the White Limestone about here rests sometimes on the metamorphic rocks and sometimes on a detrital formation of sands and gravels made from the granodiorite and its metamorphic associates. The evidence, therefore, accords with that elsewhere, namely, that the granodiorite and its associates are much the older rocks. In this section of his paper the author refuses to accept this conclusion, on two grounds: (*a*) that the granodiorite can be seen to intrude the White Limestone, and (*b*) that the gravelly formation mentioned above does not underlie the White Limestone, but is a later deposit.

As regards (*a*), his admission that there is no noticeable contact-alteration at the places where the White Limestone adjoins the granodiorite seems to me conclusive against the junction being intrusive. He attempts to explain this difficulty by assuming that the granodioritic bathylith is capable of thoroughly hornfelsing only rocks "that have fallen or become pendent in it" and has only slight effects at "the outer contact". It is for him to establish this thesis and also to explain why, among so many types of rock that have been thoroughly hornfelsed, the White Limestone type should be so conspicuously absent.

As regards (*b*), the conglomerate or gravel beds with their granitic and metamorphic contents were originally mapped by Sawkins as old river gravels of the Wagwater, and the author, by implication, but without a definite statement, appears to take the same view. My reasons for mapping this deposit as an Eocene and pre-White Limestone formation are :—

(1) The absence of limestone pebbles, although it is overlooked by the White Limestone escarpment. Its contents consist entirely of the older rocks.

(2) An impersistent band of sandy and gritty limestone lies locally in the deposit and contains corals and other marine fossils. The author suggests that it is "a calcrete of broken-up and partly dissolved White Limestone", but I am convinced that very few geologists visiting the section would agree with this view, and I hold that the fossils are contemporaneous and represent a life-colony which found a temporary footing during the deposition of this material.

(3) At Golden Hill[1] the deposit is overlain by an outlier of White Limestone, some 150 yards long. The author suggests that it is a slipped mass from the limestone escarpment, the nearest outcrop of which is 1,000 yards away. I think this great mass is in place, but the point is of little importance as a factor in the discussion, because this conglomeratic and sandy deposit can be traced in the direction of Stony Hill up to the foot of the escarpment, and there it seems to pass under the limestone.

But even if the author's view of the age of this deposit were accepted, his case would be helped to a very limited extent, because there are numerous other exposures in the Kingston district (as shown earlier in this paper) where granodiorite pebbles are found in Cretaceous and Eocene deposits.

The Hermitage Dam Area (p. 264).—The author gives a sketch purporting to show the slipping of White Limestone over what he calls "late gravel beds" which contain pebbles of granodiorite. I saw this section first (in the company of Mr. Stockley) in November, 1923, when the road on which the section lies was under construction and the cuttings were quite fresh. The limestone was then indubitably in place. I saw it next in January, 1927, and noted :—

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[1] Trechmann is mistaken in calling this place "Golden Spring" (see p. 262, footnote), which is one mile distant from Golden Hill.

"It is not so well exposed now as it was three years ago owing to slips and weathering. The limestone rests on a bed of green plastic clay, 2 or 3 feet thick, like that seen yesterday in the little side-valley above Retreat (where it is faulted against the granite), and the clay rests on a considerable thickness of coarse unstratified andesitic conglomerate of which the base is not seen. In the clay I found numerous crystals of selenite but no fossils."

I have a further note, dated 20th April, 1927, when I again looked at this section, in which I mentioned that a "thin clay" separates at least 30 feet of conglomerate from the limestone. It is possible, as the author does not mention this clay, that it is now obscured by the slipping of the limestone over its plastic base, but he can be assured that the conglomerate is not a late gravel but a true Eocene deposit and affords one of the many proofs that the granodiorite is older than the White Limestone.

The Port Royal "Laccolite" (pp. 265–6).—This "laccolite", or, as I prefer to call it, the "Newcastle Sill", is recognized to be a post-Complex intrusion into rocks of post-Complex age, so that this part of the author's paper is irrelevant to its title and appears to have been inserted in order to give a half-hearted support to Sawkins who included this mass in his "Metamorphosed series". Sawkins regarded this porphyry, wholly or in part, as a metamorphosed sandstone. The author, after an examination of some outcrops, comes to the conclusion (1936 *a*, 265–6) that there are "large-scale inclusions or assimilations of sedimentary rock [which] suggest that, although the main mass of the porphyry shows an intrusive contact, Sawkins's term 'Metamorphosed series' may be a more appropriate term for parts, at least, of it than 'Sill' or 'Laccolite'".

I should like to say that I have mapped this great porphyry intrusion on the scale of 2½ inches to the mile, and a full description will appear in my forthcoming Kingston district paper. I have myself not found evidence of large-scale assimilations.

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On a Specimen of Eusthenopteron from the Old Red Sandstone of Scotland.

By T. S. Westoll, Department of Zoology and Comparative Anatomy, University College, London.

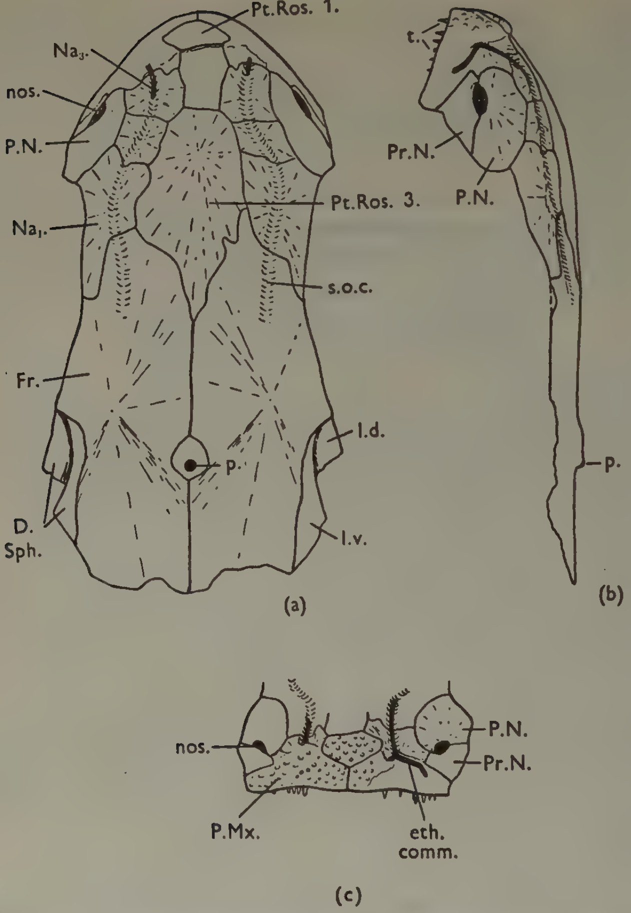
1. Introduction and Acknowledgments.

While examining the collection of Old Red Sandstone fishes in the Royal Scottish Museum, the writer found the fronto-ethmoid shield of a Crossopterygian fish, from Boghole, on the Muckle Burn, near the boundary between Elginshire and the county of Nairn. Though imperfect, the skull fragment retains its natural shape, and at once recalled the similar region of *Eusthenopteron*, from the famous fish-bearing beds of Scaumenac Bay, Province of Quebec, Canada. Further comparison seems to prove the generic identification. The stratigraphical relationships of the find are known with some precision, and the implications are of considerable importance. It is especially opportune that Dr. Erik Jarvik, of Stockholm, has just finished an account of *Eusthenopteron* species from the Baltic and Russia, with a discussion of the stratigraphy of those localities which yield the fish. Certain features of the Canadian *Eusthenopteron* are discussed in the present paper for comparison with the Scottish form: this is in no way prejudicial to the monograph on the Scaumenac Bay material, now in preparation by Dr. Jarvik.

The writer wishes to acknowledge the kindness of Dr. A. C. Stephen, of the Royal Scottish Museum, in allowing him to borrow the original and comparative material. He wishes also to thank his friend, Dr. Jarvik, for sending a proof of his paper before publication, and for some valuable comments on the variability of the Canadian material. The writer is also deeply indebted to Professor D. M. S. Watson, F.R.S., for his continued interest and help, and gratefully acknowledges a Senior Research Award made to him by the Department of Scientific and Industrial Research.

2. Description of Material.

The specimen from Boghole (Royal Scottish Museum, 1903, 63, 69) is about 6 cm. long as preserved; it consists of a fronto-ethmoid shield, undistorted, though lacking the "posterior antorbitals", "supraorbitals", and the posterior parts of the



TEXT-FIG. 1.—*Eusthenopteron traquairi*, sp. nov. Holotype, No. 1903, 63, 69 (Royal Scottish Museum). × $\frac{4}{3}$
(a) In dorsal view. (b) In left lateral view. (c) In anterior view.

Index letters used in figs. 1–5 :—

D.Sph.	Dermosphenotic
Fr.	Frontal.
I.T.	Intertemporal
Pa.	Parietal.
Na.	Nasals (with suffixes).
P.Mx.	" Premaxillary."
P.N.	Post-narial.
Pr.Fr.	Pre-frontal.
Pr.N.	Pre-narial.
Pt.Ros.	Post-rostrals.
S.O.	Supraorbital.
S.T.	Supra-temporal.
l.d.	dorsal lamina of dermosphenotic.
l.v.	ventral lamina of dermosphenotic.
nos.	External nostril.
p.	pineal foramen.
pr. d.	dorsal process of premaxillary.
scler.	sclerotic plates.
s.o.c.	supraorbital canal.
t.	teeth.

dermosphenotics and frontals. There are no visible remains of the endocranium. Most of the actual substance of the bones is missing, leaving a mould of the inner surfaces of the dermal bones. Considerable parts of the actual bones are preserved only in the snout; the "premaxillaries" (or dentigerous rostrals) and the anterior post-rostral, with some of the bones round the external nostrils, are preserved in this way, and a little of the external surface is present. There are numerous small flecks of bone elsewhere. The matrix is a pale brown and yellow sandstone of rather coarse grain, with rolled fragments of reddish mud, and with larger rounded quartz grains scattered through it. The quality of the mould is remarkably good considering this fact, and most of the sutures can be made out with complete certainty under binocular magnifiers. The structure of the specimen is indicated in Text-fig. 1, a-c.

The shield is rather convex from side to side on the whole, and anteriorly is very convex. The tooth-bearing margin of the "premaxillaries" forms an almost hyperbolic curve. The antero-posterior curvature of the skull-roof is almost confined to the anterior third of the part preserved.

The most conspicuous feature of the skull-roof is a pronounced small elevation in the mid-line, between the frontals: this marks the position of the pineal foramen, which seems to have been surrounded by a ring of small bones, but these cannot satisfactorily be separated from one another. The frontals are seen as a mould of their cranial surfaces. They are rather wide posteriorly; just in front of the pineal foramen they widen rapidly to a pair of blunt-pointed lateral projections; anteriorly the bones become gradually narrower. The centres of radiation of the frontals are rather laterally placed, between the broadest points. The dermosphenotics are only partly preserved as impressions of the ventral surfaces. Each bone shows the mould of part of a lamina, extending dorsally and laterally from the anterior part of the bone, which in life must have overlapped the postorbital; and a more posterior and ventral lamina which becomes more prominent posteriorly, but is incompletely preserved. The latter must have been overlapped by the postorbital. Similar overlap surfaces are present in *Eusthenopteron foordi*, and have been described by Jarvik in *E. säve-söderberghi*. Anteriorly the frontals meet paired nasals along very oblique sutures, and are embayed in the middle line to receive the posterior member of the post rostrals. The posterior nasal on each side is a large element, with a long process extending posteriorly, lateral to the frontal. The nasal series is completed by two pairs of smaller, rather square elements. On each side, the three nasals meet laterally an almost semicircular bone, also largely preserved as a mould of its inner face; this is the post-narial (= "anterior antorbital"—see below), which embraces the dorsal margin of the external nostril.

The anterior margin of the skull is formed by a pair of "premaxillaries" (dentigerous rostrals, Westoll, 1936, p. 165):

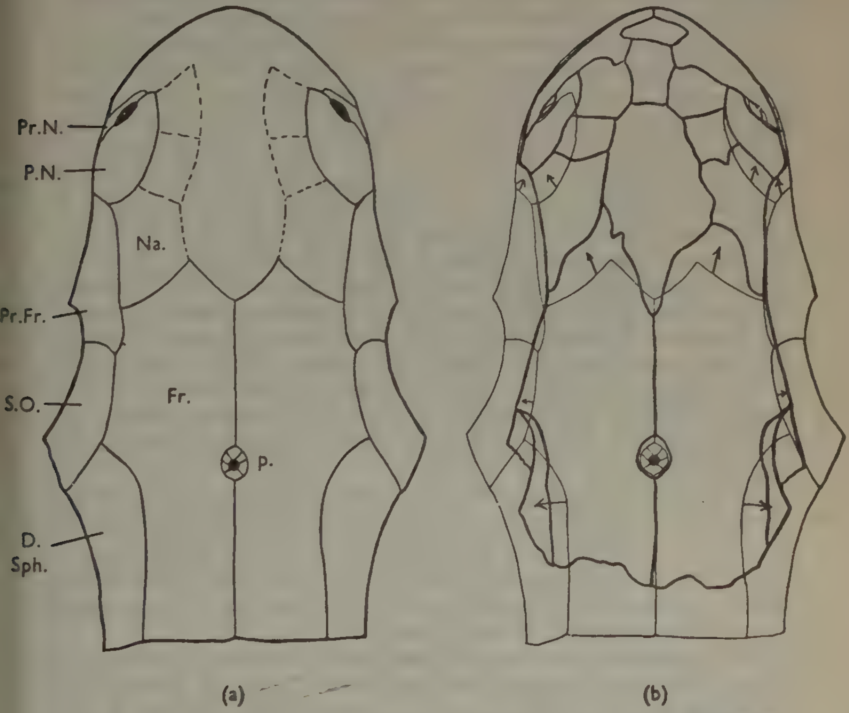
near the margin these are clearly formed of very thick bone, but there is a wide dorsally-directed process of the same general thickness as the adjacent nasals and post-rostrals. The visible margin of the bone bears a number of pointed conical teeth of rather small size: larger conical teeth, such as are present on the thickened internal margin of the "premaxillary" of *Eusthenopteron foordi* Whiteaves (see below) have not been exposed, though they may be present. Between the premaxillaries and the post-narial is a small bone, the pre-narial (see below), wider laterally than mesially, forming the ventral margin of the external nostril; it is considerably inrolled at this margin. Between the frontals, nasals, and "premaxillaries" is a series of three unpaired post-rostrals, as shown in the figures: the most anterior member separates the two broad dorsally directed processes of the "premaxillaries".

The most anterior post-rostral and parts of the premaxillaries retain little of the external surface. This is too restricted to enable an accurate idea of the whole ornament to be obtained, but as in *E. foordi* it consists of rounded tubercles, often partly confluent at their bases.

The supraorbital latero-sensory canals are shown clearly in the anterior part of the skull, and are situated rather deep in the bones, causing pronounced grooves on the moulds of the internal faces of the nasals; in the frontals these grooves become fainter posteriorly, and cannot be traced behind the centres of the radiate structure. The canal runs from near the centre of radiation of the frontal through the centres of radiation of the nasals on each side, and passes into the dorsal process of the "premaxillary". In the nasals the canals sweep outwards in a slight curve, and approach one another again anteriorly. The actual filling of the canal can be seen in the most anterior nasal and the premaxillary on each side.

At or near the radiation centre of the left "premaxillary", the left supraorbital canal can be seen to anastomose with the ethmoid commissure. This is only partly exposed, and runs laterally a short distance towards the bone forming the ventral margin of the nostril. It then turns downwards and appears to end in the narrow lateral part of the "premaxillary". The canal on the other side has not been prepared, as such an action would damage one of the few remaining areas of bone surface. A group of pores of the latero-sensory system is shown on the right "premaxillary".

It is now necessary to compare this specimen with *Eusthenopteron* from Scaumenac Bay. In this comparison I have used five specimens showing the fronto-ethmoid shield: three from the Royal Scottish Museum (Nos. 1887, 20, 17; 1887, 20, 20; and 1897, 51, 198), and two figured by Säve-Söderbergh (1933, pl. 15, fig. 1; pl. 16). The fronto-ethmoid regions of three of these specimens are shown in cranial view, the other two from outside. It is clear that many of the sutures are strongly overlapping, so that in the same individual the shape of the bones may be different on the two faces. Besides this there is variation in the number and arrangement of certain groups of bones; these differences may be rather haphazard, e.g., the post-rostrals, or they may immediately be explained by fusion of adjacent lateral-line elements, e.g., the posterior nasals. There is also an important variation in the proportions of the fronto-ethmoid shield: one of my specimens (1887, 20, 17), has about the same proportions as the Scottish specimen, but others are distinctly broader. Until Dr. Jarvik's monograph is completed it is impossible to assess the value of this latter variation: there may be more than one species, or there may be a very interesting case of variability. It will be sufficient for the moment to show that the Boghole specimen can be compared in proportions with certain individuals from Scaumenac Bay, and has the same anatomical structure.



Text-fig. 2.—(a) Fronto-ethmoid Shield of *Eusthenopteron foordi*, Whiteaves, Scaumenac Bay, Quebec. Uncrushed, in plan. $\times \frac{4}{3}$ No. 1887, 20, 17, Roy. Scottish Mus. (b) Same (thin outline) with *E. traquairi* reduced to same length between front of head and pineal foramen, and superposed.

The most slender Scaumenac Bay fronto-ethmoid shield available is luckily complete and practically uncrushed (1887, 20, 17, see fig. 2 a). The sutures are not easy to see on the surface, but those which can be seen under xylol are indicated. In Text-fig. 2 b the Boghole specimen is superposed on an outline of 1887, 20, 17, so that the length from the anterior margin to pineal foramen is the same: it will be seen that the fit is fairly good anteriorly, but not very good behind. This is largely due to the strongly overlapping sutures.[1] From the examination of other specimens it is possible to ascertain the direction of overlap: and in Text-fig. 2 b the small arrows indicate the direction and approximate relative magnitude of the shifts from external to internal sutures in a few places.

The frontals in the Scaumenac Bay material are usually distinctly broader than in the Boghole specimen, except in No. 1887, 20, 17. A more noteworthy difference concerns the position of the pineal foramen, which in the Canadian material is situated between the centres of radiation of the frontals: the broadest part of the bones may be just behind this level. One specimen figured by Säve-Söderbergh (1933, pl. 15, fig. 1), has the broadest part of the frontals just in front of the pineal; this is also the case with No. 1887, 20, 17. The Scottish specimen differs in the distinctly more posterior position of the pineal with respect to the centres of radiation and the broadest part of the bones. On the inner surface of each frontal of the Canadian material is a slight ridge passing postero-mesially from the radiation centre behind the pineal. This is duplicated in the Boghole specimen. The ridge on the inner surface of each frontal, marking the course of the supraorbital sensory canal, can only be traced in the anterior parts of the bone in both Scotch and Canadian forms.

The number of nasals in Scaumenac *Eusthenopteron* is often three on each side, the posterior member being large and occasionally divided into two (cf. Säve-Söderbergh, 1933, p. 108, pl. 16; fig. 4 b of this paper). The Boghole specimen shows three nasals, the posterior member being large. The relation of these bones to the post-narial (= anterior antorbital) is similar in all.

The external nostril is surrounded in the Canadian forms by two dermal bones—a postero-dorsally placed "anterior antorbital" (cf. Säve-Söderbergh, 1932, p. 75; Stensiö, 1922, p. 1248, fig. 3; Westoll, 1936, p. 164; Jarvik, 1937, p. 75), here called *post-narial*, and a more antero-ventral bone, called a "lateral rostral" by Jarvik (1937, esp. p. 103, p. 119), and here called *pre-narial* (see below). The latter rests in an excavation in the dorso-lateral margin of the "premaxillary", and is very strongly inrolled at the nostril opening. The Boghole specimen shows similar conditions (Text-fig. 1, b, c). The relation to the ethmoid commissure is apparently rather different in the two forms, however, and will be discussed below.

The "premaxillary" (dentigerous rostral) in Canadian material

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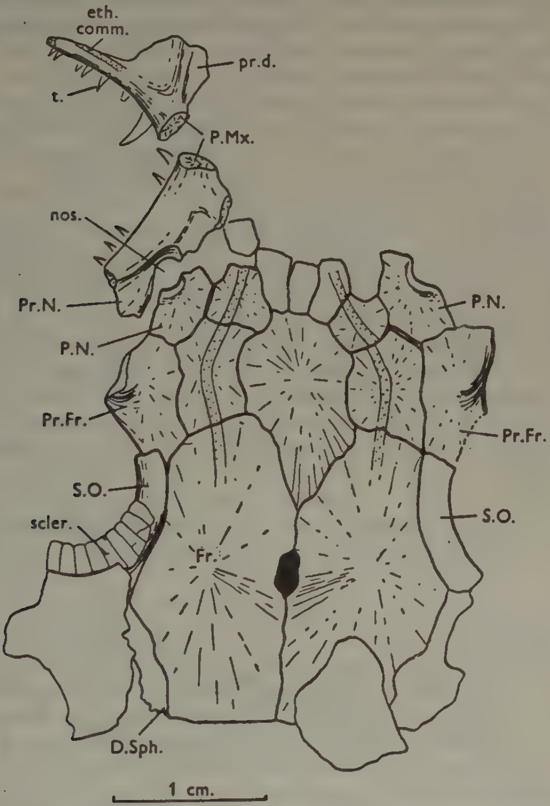
[1] If the two specimens are reduced to the same length between the front of the snout and the centres of radiation of the frontals, the fit is a little better.

(Text-figs. 3, 4 a) is strongly thickened near its margin, and meets its fellow in a strong symphysis. It bears near the symphysis, on the thickened internal face, a large tooth, and a marginal series of smaller teeth. There is a rather wide dorsal process of the "premaxillary", consisting of a thickened rib through which the anterior end of the supraorbital canal passes, and thinner lateral flanges.



Text-fig. 3.—*Eusthenopteron foordi* Whiteaves. Fronto-ethmoid region of No. 1887, 20, 20, Roy. Scottish Mus., internal view.

The Boghole specimen also shows the "premaxillaries" with thickened ventral parts, and the dorsal processes are like those seen in Scaumenac Bay material.

The ethmoid commissure in the Canadian specimens at my disposal runs laterally from the anastomosis with the supraorbital canal at the radiation centre of the "premaxillary", and passes out through the dorsal part of the shallow lateral portion of that bone. In this region it seems most probable, from my material, that the canal actually ran in a groove in the dorsal margin of the "premaxillary", and thus between the "premaxillary" and narial bones. Jarvik (1937, particularly p. 119 and fig. 6) has shown the canal passing through the extreme ventro-lateral margin of the "lateral rostral"; I am unable to confirm this on my material, and it seems certain that the canal does not pass through the centre of radiation of the bone, which is situated at the place where the bone begins to roll in at the nostril margin. This point will be further discussed below, and for the moment the above evidence will suffice to show that the bone is not a lateral rostral, and that any relation the bone may have to the ethmoid commissure is secondary and fortuitous. In this connection the Boghole specimen is very instructive, as it is clear that the ethmoid commissure runs laterally as though to enter the suture between the "premaxillary" and the "lateral rostral", and then turns ventrally and ends blindly.

The post-rostrals in Canadian *Eusthenopteron* are variable in number, as will be clear from the figures (Text-figs. 3, 4), but the area they occupy is always widest between the posterior pair of nasals. The same is true of the Boghole fish.

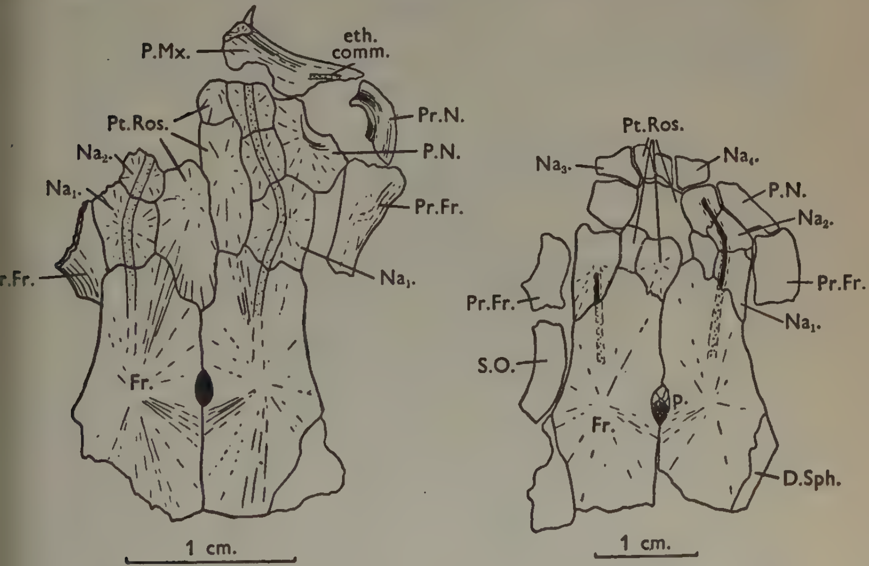
The post-rostrals are very variable in number and detail in other Rhipidistia (e.g., *Osteolepis*, Westoll, 1936, p. 165): their arrangement seems to be a purely individual matter, and although none of the Canadian material available to me shows exact similarity to the Boghole specimen, this cannot be regarded as a valid point of separation.

The outward sweep of the supraorbital canals in the posterior nasals is small in *Eusthenopteron foordi* as compared with many other Rhipidistia, and this peculiarity is found also in the Boghole specimen.

Jarvik has recently described two European specimens of *Eusthenopteron*; one (formerly described as *E. foordi* by Gross, 1936, p. 69, Abb. 1–5, 8 and Abb. 9, fig. 2, 3), from the *Bothriolepis cellulosa* marls of Kokenhusen, Livonia (*Eusthenopteron säve-söderberghi* Jarvik), and the other (based on the skull-portions described by Rohon, as *Cricodus* (*Polyplocodus*) *wenjukowi* (1889, taf. 1, figs. 3, 4, 6, 11), and *Dendrodus biporcatus* (*in errore*, 1889, taf. 1, figs. 1, 5, 9)), from the Lower Upper Devonian of Juchora, on the River Sjass, Russia.

E. säve-söderberghi Jarvik is extremely like *E. foordi* in very many ways, and resembles the broader forms from Scaumenac Bay in particular. It is said to be distinguished from *E. foordi* by the following characteristics: "A closer arrangement of the tubercles on the external face of the dermal bones . . .; a greater extension backwards of the nasal series; the presence of a short suture between the most posterior part of the nasal series and the most anterior part of the posterior supraorbital; a shorter (about $\frac{4}{5}$ of the length in *E. foordi*) supraorbito-antorbital (and a correspondingly lengthened posterior supraorbital) ; and larger and somewhat differently arranged pineal plates" (*op. cit.*, p. 89). Of these points, the second and third are shown also in some Canadian specimens (cf. Säve Söderbergh's specimen, 1933, pl. 16 (Text-fig. 4 B of this paper), and No. 1887, 20, 20 (Text-fig. 3)), and the species is clearly very close to *E. foordi*. The length of the anterior part of the cranium of *E. säve-söderberghi* is about the same as in the Boghole skull.

Eusthenopteron wenjukowi is very much larger—twice as long as the Boghole specimen, and one and a half times as big as the largest *E. foordi*. Its state of preservation is such that it cannot be compared closely with the Scottish fish, as only parts of the dermal bones are preserved.



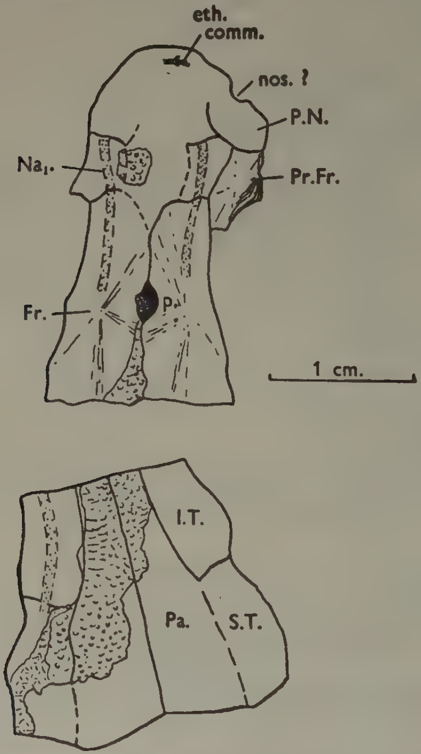
(a) (b)

Text-fig. 4.—*Eusthenopteron foordi*, Whiteaves. Fronto-ethmoid regions in internal view:

(a) of No. 1897, 51, 198, Roy. Scottish Mus.,
(b) from Säve-Söderbergh, 1933, pl. 16, fig. 1.

Thus in all essential anatomical features the Boghole skull resembles *Eusthenopteron foordi* Whiteaves, and in proportions is very similar indeed to certain individuals at present included in the latter. It is, however, more slender than the average specimen from Scaumenac Bay, and differs in the more posterior position of the pineal foramen with respect to the centres of radiation of the frontals. In these features it also differs from *E. säve-söderberghi*. No useful comparison with *E. wenjukowi* can be made, but the Scottish specimen is of far inferior size.

It is proposed, therefore, to place the Boghole fish in a new species, which may appropriately be called *Eusthenopteron traquairi*, sp. nov. The diagnosis of the new species is necessarily very imperfect : " A species of *Eusthenopteron* of moderately large size, the skull of rather slender proportions. The pineal foramen situated behind the centres of radiation of the frontals. External ornament of the bones of the snout consisting of rather low, broad tubercles, partly confluent at their bases " (Holotype, No. 1903, 63, 69, Royal Scottish Museum, Edinburgh).



Text-fig. 5.—*Tristichopterus alatus*, Egerton. Skull of No. 1875, 29. 215, Roy. Scottish Mus., figured by Traquair, 1875, pl. 32, fig. 2.

The closest relative of *Eusthenopteron* is undoubtedly *Tristichopterus alatus* Egerton, and the short summary of their relationship given by Jarvik (1937, p. 64 *et seq.*) has shown that the differences are even slighter than is usually believed. The only important difference in the skull noted by Jarvik is the proportional length of the fronto-ethmoid and parietal shields, which is 1·85 in *E. foordi*, 1·4 in *Tristichopterus alatus*. The present writer has attempted, in vain, to find distinguishing cranial features, perhaps owing to the imperfection of the material of *Tristichopterus*, and gives a figure of the head of a fine specimen[1] (No. 1875, 99, 215) in the Royal Scottish Museum to illustrate the similarity in essential features (Text-fig. 5). The fronto-ethmoid shield is more slender than in the average *E. foordi*, and in this is closer to *E. traquairi*. The pineal foramen, however, is between or slightly in front of the radiation centres of the frontals, and *T. alatus* does not attain half the size of *E. traquairi*. It is unfortunate that no parietal shields of the latter fish are known from Boghole, but there can be little doubt that the species is to be referred to *Eusthenopteron* rather than to *Tristichopterus.*

3. REMARKS ON BONE-NOMENCLATURE.

Certain of the names applied by Jarvik to bones in the *Eusthenopteron* skull call for comment. The particular bones dealt with here are those called "supraorbito-antorbital", "anterior antorbital", and "lateral rostral" by Jarvik.

The "supraorbito-antorbital" is "so called because it is formed by the fusion of an anterior supraorbital and a posterior antorbital" (*op. cit.*, p. 75). This statement is based apparently on Säve-Söderbergh's interpretation of Ichthyostegids (1932): in these primitive Devonian Stegocephalians, Säve-Söderbergh claimed to recognize three bones, not related to the lateral line system, above each orbit—two supraorbitals and an antorbital (the posterior antorbital). This condition is shown only in the specimen of *Ichthyostega stensiöi* (*op. cit.*, pls. i-iii), and, very doubtfully, in *I. watsoni* (*op. cit.*, pl. vi, fig. 1). On the other hand it is not shown in the very well preserved *Ichthyostegopsis wimani* (pl. xvi, fig. 1; pl. xvii, fig. 1, pl. xviii, figs. 1, 2), or in *Ichthyostega ? kochi* (pl. xx, pl. xxi, fig. 2), in which a single bone covers the area occupied by the alleged anterior supraorbital and posterior antorbital in the other two species. The figures of *Ichthyostega stensiöi* cited above seem to show that the apparent suture between the bones is a false appearance: it can be seen that the suture in question is a continuation of an apparent line of disturbance in the "naso-postrostral": moreover, the radiate structure of the "posterior antorbital" is centred just on the other side of the "suture", in the "anterior supraorbital". There can, therefore, be little doubt that the apparent suture is a crack and that there is a single bone occupying the position of the two recognized by Säve-Söderbergh. The specimen of *I. watsoni* is too badly preserved to be of value in discussing this region:

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[1] Figured by Traquair, 1875, pl. 32, fig. 2.

Säve-Söderbergh refers (p. 30) to the distortion of the specimen, and in particular to the distortion of the posterior antorbitals (p. 35). The writer has been able to examine the material of the Ichthyostegids in Stockholm, thanks to the courtesy of Dr. Säve-Söderbergh, and is convinced that the re-interpretation of the material advanced herein is correct.

This being so, it is at once clear that Säve-Söderbergh's extension of his interpretation of this region to the later Labyrinthodont Stegocephalians is erroneous : the homologies between the Osteolepid, Ichthyostegid, and Labyrinthodont supra- and pre-orbital regions are as follows :—

Osteolepid supraorbital = " Posterior supraorbital " of Säve-Söderbergh's interpretation of Ichthyostegids (1932).
= " posterior supraorbital " or " supraorbito-dermosphenotic " of his account of Labyrinthodonts (1935).
= post-frontal of earlier writers' descriptions of Tetrapods.
Osteolepid " posterior antorbital " = " anterior supraorbital " + " posterior antorbital " of Säve-Söderbergh's interpretation of Ichthyostegids (really a single bone).
= " anterior supraorbital " of his interpretation of Labyrinthodonts (1935).
= prefrontal of earlier writers.
Osteolepid lacrimal = " lachrymal " of Säve-Söderbergh's interpretation of Ichthyostegids (1932).
= " posterior antorbital " of that author's interpretation of Labyrinthodonts (1935).
= lachrymal of earlier writers.

The fusion between " lachrymal " and " maxillary " postulated by Säve-Söderbergh in Labyrinthodonts is thus unnecessary : there is, of course, no other evidence for such a fusion.

The " supraorbito-antorbital " of Jarvik's account of *Eusthenopteron* should therefore be called simply " posterior antorbital " in the nomenclature used by the Swedish writers (but see below).

The bone called " lateral rostral " by Jarvik borders the ventral part of the external nostril, and has, according to his account, the relationships of the Tetrapod septo-maxillary. Jarvik describes the bone as containing part of the " ethmoid commissure of the infraorbital lateral line " ; the material described in the present paper shows that the canal was probably enclosed between the " premaxillary " and the " lateral rostral " in at least some specimens of *E. foordi*, though the specimen of *E. traquairi* shows that the " lateral rostral " may have nothing to do with the ethmoid commissure. The occasional surrounding of the lateral part of the commissure by the so-called " lateral rostral " can thus be understood without difficulty as a matter of differential growth of the bones, but the relationship between the " lateral rostral " and the canal is not a primary one : the canal does not traverse the growth centre of the bone so far as the writer can observe.

There is a bone of similar relations to the so-called "lateral rostral" developed in *Megalichthys* and *Ectosteorachis* (author's observations). In *Megalichthys* from the British Coal Measures the bone has no relation whatever to the ethmoid commissure which passes completely antero-ventrally to the bone. The conditions in *Megalichthys* are otherwise so similar to those in *Eusthenopteron* that there can be no doubt of the homology: the major difference is in the larger size of the bone, and its contact with the more anterior nasals, in the former fish. These differences, together with the relative diminution of the "anterior antorbital", are clearly connected with the much more postero-dorsal position of the external nostril in *Megalichthys*. In the face of this evidence, the writer is driven to the conclusion that the bone cannot properly be named "lateral rostral", which should signify a *primary* relationship to the ethmoid commissure: it is proposed, therefore, to use the name *pre-narial* for this bone, which Jarvik believes to be probably the homologue of the Tetrapod septomaxillary.

As regards the nomenclature of the "antorbital" elements, some comment seems necessary. The typical fish in which the "antorbital" was described is *Amia calva* (cf. Sagemehl 1884, Allis 1889 and 1898, Pehrson 1922). Here the antorbital is related to the two most lateral organs of the ethmoid commissure and the two most anterior organs of the infraorbital latero-sensory canal[1] (cf. Allis, 1889, and Pehrson, 1922), and as Pehrson has shown, it develops in primary relationship to these organs. Hence it includes elements in part, at least, homologous with the anterior part of the lacrimal and the lateral part of the rostrals of a Rhipidistian. It follows that the name "antorbital" cannot be applied to the Rhipidistian bones called by almost all recent authors "anterior and posterior antorbitals". Jarvik (1937, p. 77) describes a group of ramifying tubules which "appear to issue from the centre of radiation" of the "supraorbito-antorbital"; in certain other fishes (notably Dipnoi) studied by the present writer a lateral line tubule may enter some bone not related to the latero sensory canals, and may give rise in that bone to just such a radiate group of smaller tubules. In view, therefore, of Jarvik's statement (*op. cit.*, p. 77), that he was not able to observe the "postnasal connection" with certainty in *Eusthenopteron foordi*, which he has studied in detail, the evidence seems too slender to suggest even this connection: it should further be pointed out that the "post-nasal connection" proper in *Amia* is in soft tissue *between* the frontal and the antorbital, and the latter bone is a true lateral-line element.

The arguments outlined above show that the bone usually called "posterior antorbital" (= "supraorbito-antorbital" of Jarvik) is the direct homologue of the Tetrapod prefrontal, and the writer will have occasionally in the near future to show that the bone called "supraorbito-dermosphenotic" in primitive Tetrapods has in fact no dermosphenotic component, and corresponds strictly to the Rhipidistian supraorbital; it is the bone called "post-frontal" by earlier writers on Tetrapods. It should, therefore, be possible to use these Tetrapod names in Rhipidistia, the homologies being now demonstrated as follows:—

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[1] The writer interprets the latero-sensory canals of the snout of *Amia* as follows: Organs Nos. 1, 2, 3, and 4 of Pehrson's fig. 16 belong to the ethmoid commissure; Nos. 5 and 6 represent the front of the infraorbital canal dragged upwards with the nasal pit (cf. particularly Allis, 1889, pl. xxx).

Prefrontal = posterior antorbital of most writers on Rhipidistia
= supraorbito-antorbital of Jarvik
Postfrontal = supraorbital of most writers on Rhipidistia
= posterior supraorbital of Jarvik

Unfortunately the term "postfrontal" has been used in very many different ways in fishes, and it may be more convenient to use the term "supraorbital" for the bone in Rhipidistia.

4. Stratigraphical Relationships.

The stratigraphy of the Muckle Burn area is described in the Geological Survey Memoir on the Lower Findhorn and Lower Strath Nairn districts (Horne et al., 1923, p. 80–81). The basal conglomerates of the Upper Old Red Sandstone are followed by coarse, grey, false-bedded friable sandstones containing *Asterolepis maxima* near Glenshiel. The stream sections between Whitemire and Earlsmill (Boghole is between these places) show sandstones dipping generally slightly downstream and apparently unbroken by important faults. Boghole should therefore be slightly higher than Whitemire in the series. The faunas collected from Whitemire and Boghole are as follows:—

Whitemire.	Boghole.
Psammosteus taylori Traq.	*Psammosteus taylori* Traq.
Cosmacanthus	*Asterolepis alta* Traq. (M.S.).
Asterolepis maxima Ag.	*Holoptychius nobilissimus* Ag.
Bothriolepis major Ag.	*H. decoratus* Eichw.
Conchodus	*Polyplocodus*.
Holoptychius nobilissimus Ag.	*Coccosteus magnus* Traq.

(*Op. cit.*, p. 81: determinations by Dr. Traquair.)

"An examination of the foregoing list shows that it contains some forms which Dr. Traquair regarded as peculiar to the Nairn beds and others which he considered to be specially characteristic of the Alves sandstone in Morayshire" (*op. cit.*, p. 81).

Although Boghole should be on a slightly higher horizon than Whitemire, no *Bothriolepis* is recorded from the former locality. There may, of course, be minor faulting: but both localities must be very near the level of the first appearance of *Bothriolepis*.

The Livonian form *Eusthenopteron säve-söderberghi*, Jarvik comes from the *Bothriolepis cellulosa* marls of Kokenhusen. This is the earliest appearance of *Bothriolepis* in the Baltic region. The important elements of the associated fauna are—

Psammosteus ? serrulatus Ag.
Coccosteus sp.
Bothriolepis cellulosa Pander.
Dipterus spp.
Osteolepis grewincki Gross.
Rhadinichthys cf. *devonicus* Clarke.

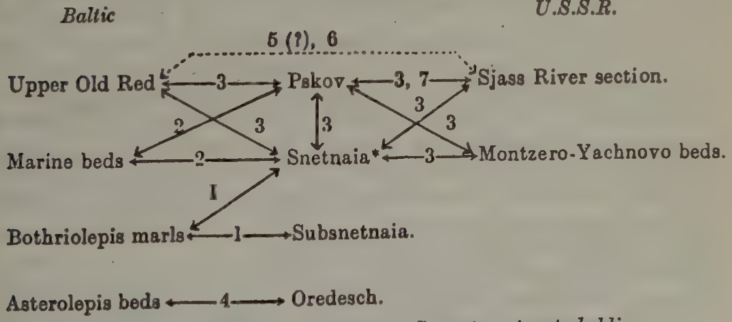
(From Gross, 1933, p. 69.)

The Russian *E. wenjukowi* (Rohon) is from the Upper Variegated series of Juchora, on the River Sjass, Russia. Jarvik has given a tabular summary of the Russian deposits (1937, pp. 120–1): the fauna of the Sjass River section is given as—

Dyptychosteus tesselatus.
Bothriolepis panderi.
Coccosteus trautscholdi.
Holonema radiatum.
Eusthenopteron wenjukowi.
Holoptychius giganteus
H. nobilissimus.
Dipterus verneuili.

Jarvik has given in the same table the "typical" Russian section: it seems clear that the table is not intended to represent exact horizontal equivalence between the Russian beds. Thus the Sjass River section is clearly closely similar in many faunal elements to the Pskov beds (*Dyptychosteus*, *Bothriolepis panderi*), and to the "Upper Old Red" of the Baltic States. The following table indicates the correspondence of some faunal elements.

TABLE 1



1. *Bothriolepis cellulosa.*
2. *Ptyctodus obliquus.*
3. *Bothriolepis panderi.*
4. *Asterolepis ornata.*
5. *Coccosteus trautscholdi.*
6. *Holoptychius giganteus* an *nobilissimus.*
7. *Dyptychosteus.*

*Marks last appearance of *Asterolepis* in the Russian series.

The Baltic "Upper Old Red", Pskov, and Sjass River beds seem to correspond essentially with the Alves and Scaat Craig beds of the Moray Firth; though as they have clearly affinities also with earlier horizons (*B. panderi*) they are probably equivalent to the lower part of the Alves beds.

The Scaumenac Bay beds (Escuminac formation of the Canadian Geological Survey, Alcock, 1935) must be placed at the very base of the *Bothriolepis* zone: although no *Asterolepis* is known from these beds, the last of the Anaspida (*Euphanerops longaevus*), Cephalaspids (*Cephalaspis laticeps* and other species), and *Cheirolepis canadensis* occur in these beds—relics of earlier faunas. Moreover, recent work in the plants of the Escuminac formation (Arnold, 1936) has shown the existence of some points of resemblance to the floras of the Middle Devonian. Spores with "peculiar grapnel-like bifurcations at the tips of the appendages" appear to be identical with spores from the Middle Old Red Sandstone of Cromarty and the Middle Devonian of Elberfeld (Lang's spore-type G.). "Certainly some significance may be attached to the occurrence at Scaumenac of the appendaged spores, though their affinities are not known. At Cromarty, where the type was first found, it occurs with Middle Devonian types, such as *Hostimella* and *Palaeopitys*. At Elberfeld the spores are associated with *Aneurophyton germanicum, Asteroxylon elberfeldense, Cladoxylon scoparium, Hyenia elegans, Calamophyton primaevum*, and other forms, indicating an overlapping of early and late Devonian floras. *Archaeopteris* does not occur at either of these localities, but the occurrence of this spore at Scaumenac suggests that there are some elements in common between the Middle Old Red and Elberfeld floras and the Archaeopteris flora of Eastern Canada, which are not yet fully known. Whether the Scaumenac beds are older than are commonly supposed or whether the Middle Devonian European types persisted during later times in the Western Hemisphere can be determined only after further investigations have been carried out" (Arnold, 1936, p. 45–6).[1] Hence, several factors combine to show that the Escuminac formation must belong to the very base of the *Bothriolepis* zone, the lowest part of the Upper Devonian.

Thus to summarize the stratigraphical conclusions, species of *Eusthenopteron* occur in Canada (*E. foordi* Whiteaves), Scotland (*E. traquairi*, Westoll), and Livonia (*E. säve-söderberghi*, Jarvik) at the base of the *Bothriolepis* zone, and thus at the extreme base of the Upper Devonian. A fourth species occurs in Russia (*E. wenjukowi*, (Rohon)), at a level somewhat higher in the *Bothriolepis* zone, but probably still in the lower part of that zone.

The conditions of sedimentation in the Scottish locality are very different from those in the *Bothriolepis* marls of Livonia and the similarly fine-grained beds of Scaumenac Bay: this fact makes the recognition of the appearance of *Eusthenopteron* with *Bothriolepis* at all three localities very important, as it increases the value of both forms as zonal indices.

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[1] But Arnold points out that spore-type G. occurs in beds possibly of Chemung age.

As Dr. Jarvik's work has shown that *Tristichopterus alatus* is very closely allied to *Eusthenopteron*, it may be of use to refer briefly to the stratigraphical position of the John o' Groats beds and Eday Flags which yield this form in Caithness and Orkney respectively. In Caithness the fauna of the highest members of the Thurso Flagstone group is not very well known, but *Asterolepis* has not been described from it. In Orkney, Watson (1932) has described a species (*Asterolepis orcadensis* [1]) from the top of the Rousay Flags, a short distance below the Eday Flags. Moreover, in Shetland specimens of *Microbrachius*, like *M. dicki* from John o' Groats and the Eday Flags, occur in the Brindister flags, which contain *Asterolepis thule* not far away. It seems possible, therefore, that the *Pentlandia-Tristichopterus-Microbrachius* fauna should be placed in the *Asterolepis* zone, rather than across the junction between that zone and the Middle Old Red Sandstone, as it is usually done. This would bring them stratigraphically closer to the *Eusthenopteron* level, but there is need of much more positive evidence on this point.

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[1] Watson has pointed out that this species is rather peculiar, and in some respects resembles *Bothriolepis*. *Mem. Geol. Surv., Summary of Progress* for 1931 (1932), 161.

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REVIEWS.

The Permanence of Oceanic Basins and Continental Masses. By Sir Thomas H. Holland. Huxley Memorial Lecture, 1937. pp. 22. London: Macmillan and Co., Ltd. Price 1*s*.

In this brilliant lecture Sir Thomas Holland takes as his text the famous Presidential Addresses to the Geological Society given by Huxley in 1870 and by his own predecessor, W. T. Blanford, in 1890; on this basis he builds up a fascinating sketch of the development of ideas on the relation of continents and oceans to the distribution of animal and plant life in the past and cognate problems. From his own long experience in India Sir Thomas is obviously well fitted to appreciate the significance of Gondwanaland. In many parts the treatment is refreshingly unorthodox and a famous remark of Huxley is quoted concerning the damping effect of the floods of cold water that have flowed from Burlington House over geological speculation. After all it is difficult to see how any progress can be achieved without speculation: the rest is but a pile of dry bones. Nevertheless the lecture is to some extent a plea for a suspension of judgment, especially by mathematicians and physicists, until geology has had time to pile up more facts, and to show what did happen, which is not the same thing as what ought to have happened according to some particular theory. However, it is obvious which way the lecturer's sympathies go, and he pays a special tribute of admiration to the work of Dr. du Toit in South Africa and South America, stating expressly that the likeness between these continents can, in his opinion, only be explained on the assumption that they were once close together, if not actually in contact. There are hopes yet for the doctrine of continental drift if a few more people of light and leading would only get down to brass tacks like this.

Field Tests for Minerals. By E. H. Davison. pp. 60 with xii plates. London: Chapman and Hall, 1937. Price 7*s*. 6*d*.

Profiting by his long experience as a teacher of mineralogy to mining students at Camborne, Mr. Davison has put together a most useful handbook of tests for the determination of minerals by physical and chemical methods. Elaborate optical apparatus is excluded and the tests are all such as can be carried out with a simple petrological microscope or (most of them) with a pocket-lens. The three principal categories are blow-pipe tests; tests with organic reagents; and microchemical tests; the last two sections are specially valuable as much scattered information is here collected in a handy form. The second half of the book consists of a set of tables for mineral determination largely based on hardness, lustre, colour, and streak. This book may be heartily recommended to students of mineralogy and more especially to those interested in the practical side, to whom theoretical crystallography is not the first object.

GOLD DEPOSITS OF THE WORLD. By W. H. EMMONS. pp. vi + 562, with 332 figures. London and New York: McGraw-Hill, 1937. Price 36*s*.

IN this large book Professor Emmons has brought together an enormous amount of information as to the gold mines of the world. Some idea of the number of mines described may be gathered from the fact that the index, place-names only, runs to nearly 16 pages of double column in very small type. It is obvious that great pains have been taken to get correct information and references are very numerous. The balance between different parts of the world is much better than in many American books, rather less than half of it being devoted to North America, while the description of the Witwatersrand is unusually complete. The great number of figures is also a useful feature: though some of these are rather rough, they are clear. A short chapter at the end on "Prospecting" is of special interest, as it gives an excellent summary of the conditions under which gold deposits most commonly occur, with special stress on cupolas and roof-pendants as the location of primary ore-bodies. This of course applies to very many metals besides gold. Any attempt at detailed criticism would be out of place; all classes of readers, from students to specialists, will here find what they want.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY.

24th June, 1937.

(1) "Wollastonite solid-solutions from Scawt Hill, Co. Antrim." By Professor C. E. Tilley.

Wollastonites with distinctive optics comparable with those of synthetic solid solutions in the system CaO-FeO-SiO_2 are recorded from hybrid rocks (wollastonite-bearing dolerites) of the Scawt Hill contact zone.

(2) "Notes on silicate synthesis with a laboratory gas furnace." By Dr. A. T. Dollar.

Comparisons are made between methods of synthesizing silicates, in a high-temperature research laboratory, with (*a*) a Fletcher gas-blast crucible furnace, and (*b*) a vertical electric crucible furnace of platinum resistance type, having approximately the same dimensions. The utility of the gas furnace is discussed in relation to the bulk, homogeneity, rate of production, and cost of silicate melts which it yields. Technical details are illustrated by reference to the preparation of diopside glass.

(3) "Some new pyroxenes included in the system clinoenstatite, clinohypersthene, diopside, hedenbergite." By Mr. W. A. Deer and Mr. L. R. Wager.

Four pyroxenes from the Skaergaard Halvoen intrusion, Kangerdlugsuak, East Greenland, have been analysed. They occur in a series varying from a hypersthene-olivine-gabbro at the base to a fayalite-quartz-gabbro at the top of the crystallization-differentiated gabbro complex. The pyroxene, as well as the rocks in which they occur, show a remarkable increase in the percentage of ferrous iron. The pyroxenes are all low in sesquioxides and may be regarded as approximating in composition to members of the clinoenstatite-clinohypersthene-diopside-hedenbergite system. Two of the pyroxenes are very rich in the clinohypersthene molecule and extend the field of previously investigated natural augites. The most ferriferous type is almost a pure member of Bowen's (1935) hedenbergite-clinohypersthene solid solution series, and contains nearly 70 per cent $FeSiO_3$.

(4) "A new micro-pyknometric method for the specific gravity of heavy solids: with a note on the accuracy of specific gravity determinations." By Mr. F. A. Bannister and Dr. Max H. Hey.

A straight silica tube of ½ mm. bore, closed at one end, serves as a variable volume pyknometer. The accuracy of the method may reach about 0·5 per cent with 5 to 30 milligrams of material.

(5) "An occurrence of corundum at Fraserburgh, Aberdeenshire." By Mr. Robert Walls.

Corundum is found at several places on the coast at Fraserburgh as small, usually irregular, grains embedded in muscovite, in a biotite-felspar rock. The beds at Fraserburgh are metamorphosed sediments of the andalusite-schist-facies. It is suggested that the corundum-bearing rocks were derived from andalusite-schists (into which they pass) by the desilicating action of alkali-aluminate emanations from neighbouring pegmatites. Analogous cases in France and Australia are mentioned.

(6) "A review of the data of the Mg-Fe clinopyroxenes." By Mr. N. F. M. Henry.

The identification of clinoenstatite and clinohypersthene from igneous rocks in all the reports that have been examined rests on insufficient evidence, mainly on inclined extinctions alone. The available data for the series are summarized.

(7) "Fourteenth list of new mineral names." By Dr. L. J. Spencer.

(8) "Paragenesis of kyanite-amphibolites." By Professor C. E. Tilley, with chemical analyses by Mr. H. C. G. Vincent.

The genesis of the assemblage hornblende-kyanite in metamorphic rocks is briefly discussed. Special reference is made to the problems offered by kyanite-bearing amphibolites and eclogites of the Glenelg area (Scotland).

CORRESPONDENCE.

SIDESTRAND CHALK BLUFF.

Sir,—By last December, when I was again able to visit the recently exposed bluff at the base of the cliff at Sidestrand, it had been cut back substantially, and the top had risen out of reach over the greater part, and the length exposed was much greater. I estimated it from pacing (256 paces) as at least 150 yards long, and that was by no means a maximum, as at the west end, where it was about 20 feet high, it gradually receded from high-water mark and disappeared into the cliff without any suggestion of having come to an end.

This great length of unbroken chalk, the whole of which appeared to be capped with Crag beds, seems strongly in favour of its being *in situ* rather than an erratic.

Further, in last December, the Till, which under the Overstrand Hotel seems to be well above high-water mark, could be seen quite clearly to come down to about high-water mark at a little east of the Hotel, and then rise in a huge flat arch which came down again to about high-water mark a little west of the chalk, from which point it seemed to twist sharply up and pass over the chalk and the crag in a high arch.

R. M. Brydone.

Ivy Farm House,
Mundesley.
September, 1937.

WEALDEN PEBBLES IN THE VALLEY OF THE RIVER DARENT.

Sir,—In the course of collecting pebbles of metamorphic and other ancient rocks in the Folkestone Sands of Surrey and West Kent, the petrological examination of which is in progress, new sections in the higher gravels of the valley of the River Darent were observed, overlying the Westwood sandpits of the Titsey Estate Co., near Westerham. It was discovered that the smaller constituents of these gravels contain a remarkable proportion of indubitable Wealden rocks. The gravels lie at an altitude of about 450–500 feet O.D., and are doubtless associated with the well-known gravel at about 500 feet O.D. on the present watershed of the Darent at Limpsfield.

The discovery of pebbles derived from Wealden beds was unexpected. Topley, in "The Geology of the Weald" (*Mem. Geol. Surv.*, 1875), makes several explicit statements to the contrary, which seem to have been generally accepted to this day. For example, on page 295 it is stated "The gravels of the Darent . . . are important for this; that they, alone of the gravels of the Wealden rivers, nowhere contain a trace of material from the Weald Clay or Hastings Beds. . . . I mapped the gravels of this river with great care, and examined every section of gravel exposed—some of them repeatedly; but never succeeded in finding a single pebble of Wealden sandstone". Topley's certainty was evidently shared up to a much later date by Sir Joseph Prestwich, for in his classical paper, "On the Drift-Stages of the Valley of the Darent" (*Quart. Journ. Geol. Soc.*, 1891, p. 126), he wrote, "the drift is restricted to débris derived from its own drainage area," which he points out, "is shut out by the range of the Lower Greensand from the Central Weald."

Examination of other high-level gravels in the valley, which is not yet complete, has already shown that Wealden material is usually present in these deposits, as well as at Westwood. A search through the literature since 1891 has revealed nothing in conflict with the statements quoted above, beyond a sentence in Mr. Treacher's report of an excursion of the Geologists' Association to Limpsfield in 1908 (*Proc. Geol. Assoc.*, 1909, p. 61), which reads, "Mr. Benjamin Harrison, however, informs the writer that he has found Wealden pebbles here." To this Mr. Treacher is not now able to add any further information. But through the kindness of Sir Edward Harrison, who has preserved his father's specimens and notes, the present writer has been able to investigate the grounds for Mr. Harrison's remark. He is satisfied that the small amount of Mr. Harrison's material collected at Limpsfield in 1886 which has been preserved contains so large a proportion of Wealden pebbles as to justify a statement by Mr. Harrison that "I have been searching for and studying Wealden pebbles since 1881, and can vouch for my finds".

The contribution of Wealden Beds to the Darent gravels has an important bearing on the history of the denudation of the Weald. It is therefore intended later to publish an account of this material and of the extent of its occurrence in the Darent gravels. It may be of interest also, from an historical point of view, to include therein such further particulars as are still available of Mr. Harrison's communications of his finds to Topley and Sir J. Prestwich and of their eventual non-acceptance by those authorities.

F. GOSSLING.

2 DORNTON ROAD,
SOUTH CROYDON, SURREY.
18th September, 1937.

THE
GEOLOGICAL MAGAZINE
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ORIGINAL ARTICLES.

Founders of Seismology, IV.

By Charles Davison.

In the Geological Magazine for 1921 (LVIII, pp. 98–107, 241–250, 385–396), three papers were published on founders of seismology, of English birth—John Michell, Robert Mallet, and John Milne. The series was afterwards continued so as to include similar workers in other countries, France, Italy, Central Europe, the United States, and Japan, and the accounts were included in a volume of *The Founders of Seismology*, published in 1927. Within the last two years, we have lost three men whose work entitles them to places among the founders—Bunjiro Koto, Mario Baratta, and Richard Dixon Oldham—and I propose in the present paper to give a brief account of the life and work of each.[1]

Bunjiro Koto, the oldest of the three, was born on 4th March, 1856, at Tuwano in Japan. He was educated in the Imperial University of Tokyo, in the Institute of Geology. In 1880 he was sent by the Imperial Government to continue his studies in the University of Leipzig. Soon after his return to Japan, he was appointed professor of geology in his old university (1884). In the adjoining College of Engineering, the same office was at that time held by Professor Milne, but Koto does not seem to have come under his inspiring influence and was never a member of the Seismological Society of Japan. Koto occupied the chair of geology for more than half a century, for thirty-eight years as titular professor and for nearly fifteen years as honorary professor, and was held in "high esteem and veneration" by his colleagues and pupils. He died on 8th March, 1935.

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[1] *Tokyo Imp. Acad. Proc.*, 11, 1935, p. xiv; *Ital. Soc. Sism. Boll.*, 34, 1936, 54–6; *Roy. Soc. Obit. Not.*, 2, 1936, 111–13. Portraits of Baratta and Oldham accompany the last two papers. Fuller accounts of the earthquakes referred to in the following pages will be found in my volume on *Great Earthquakes* (1936): Mino-Owari earthquake of 1891, pp. 105–129; Tazima earthquake of 1925 and Tango earthquake of 1927, pp. 212–245; Messina earthquake of 1908, pp. 201–211; Cutch earthquake of 1819, pp. 68–76; and Assam earthquake of 1897, pp. 138–157.

The main work of Koto's life was naturally connected with geology, though he did much to promote the study of volcanos and was the author of three notable memoirs on earthquakes, the first of which may not unfairly be described as a classic of seismology. His attention was first drawn to earthquakes by the destructive Kumamoto earthquake of 28th July, 1889, which he felt while surveying in a neighbouring province. Proceeding to the central district, he found that he could trace two lines of fault by the fissures in the ground and along the slopes of hills, though the faults themselves were not clearly visible at the surface. A little more than two years later came the still more violent Mino-Owari earthquake of 28th October, 1891. As soon as the news of marked subsidences reached Tokyo, Koto left for the central district and discovered, not, as he expected, lines of fault inferred from the surface phenomena, but an extraordinary earth-rent, striking across hills and fields alike, cutting up the soft earth into enormous clods and throwing them above the surface. As he describes it, the rent more than anything else resembled the pathway of a gigantic mole. He traced this great rent for a distance of more than 40 miles, starting from the village of Katabira, and running in a north-westerly direction through the Neo valley, until he reached the mountain district that occupies the boundary between the provinces of Mino and Echizen. Here, owing to the onset of winter, he was unable to follow the line farther, but, from scattered reports, he felt little doubt that the rent continued as far as Fukui, a total distance of 70 miles. Except at one place, in the Neo Valley, where the crust on the north-east side was uplifted so as to form a scarp nearly 20 feet high, he found that the entire region on this side was relatively depressed by amounts ranging up to 10 feet and shifted to the north-west by from 3 to 13 feet. These vertical and horizontal displacements seem, he concludes, to have been the sole cause of the catastrophe.

More than thirty years later, when he was about seventy years old, the veteran geologist studied in equal detail the fault-movements that occurred with two other destructive earthquakes, those of Tazima on 23rd May, 1925, and Tango, on 7th March, 1927, tracing the courses of the faults, measuring the vertical and horizontal displacements at various points along them, and illustrating them with numerous photographs taken by himself. Thus, Koto's contributions to seismology all dealt with crust-displacements at the times of earthquakes, and it does not seem too much to claim for him that, by his first memoir, he placed the reality of such movements quite beyond dispute.

Mario Baratta, the historian of Italian earthquakes, was born at Voghera on 13th August, 1868. Towards the close of his university career, he showed a bent for the study of seismology so marked that he was admitted to the geodynamic observatory of Ischia, under the charge of Professor G. Grablovitz, and obtained a close acquaintance with the instruments then in use. On 1st January, 1892, he was appointed geodynamic assistant at the Central Office of Meteorology and Geodynamics at Rome. Here he began the long series of studies of Italian earthquakes that culminated in the principal work of his life. Several of the earthquakes examined by him were of destructive intensity, especially the Verona earthquake of 7th June, 1891, while the somewhat weaker Garganic earthquake of 1892 naturally drew his attention to the more severe shock in the peninsula of Gargano in 1627. Baratta's work at the Central Office ended in June, 1896, one of his last acts being his compilation of the notices of Italian earthquakes during the year 1895, the first of the series issued annually with the *Bolletino* of the new Italian Seismological Society.

Shortly after leaving the Central Office, he began definitely to collect data relating to the past earthquakes of Italy, spending day after day in the libraries of the country and examining the many old records that were preserved in various offices. In 1897, the first result of his inquiries was published in the *Bolletino* of the Italian Geographical Society under the title, "Materials for a Catalogue of the Seismic Phenomena in Italy (1800–1872)." About this time, he must have come under the influence of Professor G. Mercalli, then professor at the R. Liceo Vittorio Emanuele of Naples. Mercalli had himself published a catalogue of Italian earthquakes in 1883, and he afterwards investigated several important earthquakes, especially those of Ischia in 1883, Andalusia in 1884, the Riviera in 1887, Calabria in 1894, 1905, and 1907, and Messina in 1908, and also, in 1897, published two valuable monographs on the earthquakes of Liguria and southern Calabria. How much Baratta owed to the guidance of Mercalli is evident from the dedication to him of *I Terremoti d'Italia*, "with the reverence and affection of his disciple."

This great work of Baratta was written at Voghera between July, 1896, and October, 1900, and was published in the year 1901. It is a closely printed volume of 951 pages. The first part, occupying more than two-thirds of the book, contains descriptions of 1,364 earthquakes from the beginning of the Christian era to the end of 1898. Of the total number, 788 are included by Milne in his catalogue of destructive earthquakes, 83 being strong enough to destroy towns and devastate districts, and 268 to unroof and shatter buildings. In the second part, he considers the distribution of Italian earthquakes in twenty-four well-defined provinces, and gives a summary, with dates, of the earthquakes of the various zones in each. The third part, consisting of more than a hundred pages, is called "a sketch of Italian seismic bibliography" that contains the titles of nearly 1,500 memoirs. *I Terremoti d'Italia* might well have been the result of a long and well-spent life, and it is difficult to realize that it is a work finished while the author was still in his thirty-third year, difficult also to avoid the regret that the same useful labour has never been given by others in providing us with similar histories of the earthquakes in Greece or the Philippines or Japan.

In the same year, 1901, Baratta published his *Carta Sismica d'Italia*, a series of four maps on which are shown the areas most severely shaken by Italian earthquakes so far as they are known. It is a useful supplement to his book.

From this study of the distribution of earthquakes, it is perhaps only natural that Baratta should have transferred his activities to the field of geography, and, in 1908, he was appointed professor of geography in the University of Pavia. His office there was perhaps responsible for the request of the Italian Geographical Society that he should investigate on their behalf the destructive Messina earthquake of 28th December, 1908, an invitation that he gladly accepted. He proceeded immediately to Messina and made what investigations were then possible in the north of Sicily and the south of Calabria. The state of the stricken country and the preoccupations of the civil and military authorities curtailed this first visit, but he was able to return in the middle of February, when he examined the phenomena around Reggio and completed his study of the Messina district. With the aid of the Minister of the Marine, inquiries were also circulated among the harbour authorities of the Sicilian and Calabrian coasts. The ample materials thus collected occupied Baratta for several months, but, by the end of 1909, he had finished his report, one of the most detailed issued by a single investigator on any great earthquake. It was published in 1910 as a volume of 426 pages with 56 plates and maps, the first half being occupied with a description of the phenomena, and the second with their discussion. From many observations on the direction of the shock, he assigned the origin of the earthquake to two foci, both submarine, one beneath the north end of the Straits, the other nearly midway between Messina and Reggio. The sea waves were also carefully studied and their heights at many points along both coasts determined.

After 1910, Baratta seems to have diverted his attention almost entirely from the study of earthquakes, and, in the last twenty-five years of his life, produced nothing, so far as I know, to compare with his early work. He died at Casteggio on 4th September, 1935, leaving behind him as a monument his two important volumes on the earthquakes of Italy and Messina.

Richard Dixon Oldham, the son of Dr. Thomas Oldham, first director of the Geological Survey of India, was born on 31st July, 1858. He was educated at Rugby and the Royal School of Mines. On the death of his father in 1878 his intended course at Cambridge was given up, and, in the following year, he joined the Geological Survey of India as assistant-superintendent. With the Survey he was connected for nearly twenty-five years, resigning, chiefly on the ground of ill-health, in 1903. Most of his time in India was spent in the ordinary course of surveying, but, soon after his arrival, he completed his father's unfinished memoir on the Cachar earthquake of 1869, and some of his last years there were spent in studying the phenomena of the great Assam earthquake of 1897 and in writing his well-known report. On his return to Europe, he divided his time between work on the Rhone delta and on various subjects connected with earthquakes. After many years of ill-health, he died at Llandrindod on 15th July, 1936.

With his keen and vigorous intellect, Oldham threw light on many branches of seismology, but his main contribution to the science was no doubt his study of the Assam earthquake of 12th June, 1897, the great earthquake of 1897, as he preferred to call it, though its claim to the first place among known earthquakes may now be contested by the Kansu earthquake of 1920. When the earthquake occurred, the four officers at headquarters, and later on a fifth, were dispatched to collect observations, and, in the cold weather of 1897–8, Oldham made a tour through the epicentral tract, and obtained many results of surpassing interest, hampered though he was by its great area and the impassable nature of much of the country, as well as by the limited time at his disposal. The most interesting and novel results of his inquiry were those of the projection upwards of stones lying on the ground, showing that the vertical component of the acceleration was greater than that due to gravity, the survey of the Chedrang fault and the measurements of the unusual vertical displacements along it, of 32 and 35 feet, the formation of great fractures, such as the Bordwar fracture, without any dislocation of the crust, the formation of pools, and several observed changes in the landscape, by which distant objects, formerly hidden, became visible. A few years before, the trigonometrical survey of Sumatra was interrupted by the earthquake of 1892, and, on being continued, showed that horizontal displacements had occurred. The Assam earthquake was, however, the first in which the re-triangulation of the epicentral area was suggested. Though the results were to some extent disappointing, owing to the uncertainty as to the constancy of the base-line, it was clear that crustal changes must have occurred in the horizontal plane, and probable that the principal movement was one of compression in the north–south direction. Interesting observations were also made on the numerous and conspicuous landslips, on displacements of the alluvium, and on seismic seiches observed more than 300 miles away in the pools of Burma. Nor were the records of after-shocks less important, especially those kept by observers at various stations in the Central area. Their distribution has been studied in detail by M. de Montessus de Ballore, who determined the epicentres of 5,307 of the total number (5,523) of after-shocks to the end of 1898.

In one chapter of his report on this earthquake, Oldham dealt with the "unfelt earthquake", with the records obtained at eleven stations situated at distances between 4,300 and 4,900 miles from the epicentre. No conclusion in the whole report was so far-reaching as his recognition of three principal phases of motion. The first and second phases he attributed to compressional and distortional vibrations that travelled through the body of the earth, and the third to undulations passing round its surface. In 1900, the year after the publication of the report, he found the same three phases persisting in the records of six other earthquakes, four in Japan (1894–7), and the Argentine earthquake of 1894 and the Turkestan earthquake of 1897, and, a few years later, in those of the Guatemala earthquake of 1902. In these memoirs, Oldham laid the foundations of what has become an important branch of geophysics. They also provided the materials for his interesting conclusions as to the nature of the earth's interior.

In one of his latest memoirs, Oldham returned to seismology. The crustal changes that occurred with the Cutch earthquake of 1819 have long been known through the well-known chapter in Lyell's *Principles of Geology*. During the years 1880–4, the Survey of India mapped the whole district, and, from his careful analysis of the map, Oldham showed that the dislocated band is much longer than was formerly supposed, that its length, instead of being 50 or 60 miles, is at least 80, and possibly 100 miles. A second result of great interest is that the displacement of the crust on the north side was upward, and on the south side downward, and that, in either direction, the amount of displacement decreased with increasing distance from the band.

The Lower Bunter Sandstones of North Worcestershire and East Shropshire.

By F. W. Shotton.

THIS paper embodies the results of work done by the Lapworth Club of the University of Birmingham on the Lower Bunter Sandstones which, west of Birmingham, outcrop in the four areas shown on Text-fig. 6. Field work was undertaken at the end of the summer terms of 1932, 1933, and 1934, and in one or more seasons the following took part: Misses E. M. Hignett, W. Kennedy, M. E. Kirkham, J. G. Mogford, H. P. Showell and M. J. Simpson, Messrs. D. A. Bates, R. V. Browne, A. J. Butler, J. R. Cooper, M. E. Kelly, A. Ludford, Dr. F. Raw, Mr. S. H. Shaw, Professor L. J. Wills, and the writer. In the summer of 1936 there became available for study (by the courtesy of the South Staffordshire Water Company) the core of a boring in the Lower Bunter at Kinver. On material from this and from outcrops the writer made a series of grain-size analyses with the help of Mr. H. B. Whittington and Mr. S. J. Martin.

The Lower Bunter had long excited attention by reason of its uniformity of composition and amazing current-bedding, and it had generally been accepted as aeolian in origin. No systematic examination of the false-bedding nor of the grading of the sediments had, however, been undertaken. The Lapworth Club considered that such a detailed investigation might prove of value and not only throw further light on the mode of origin of the deposit but also possibly produce results of importance in the general questions of cross-bedding and grading of sediments. Although the mechanical analyses were the last part of the work to be done, it will be more convenient to consider these results first.

I. The Composition of the Lower Bunter.

At outcrop the Lower Bunter consists generally of fine-textured false-bedded sands of a dull red colour—a colour which is not the result of surface weathering, for it occurs equally in deep bore-holes. Occasionally yellow sands occur, but the idea of a constant variation in colour embodied in the term "Lower Mottled Sandstone" is completely erroneous in this area. Quartz grains, each with a very thin pellicle of red iron oxide, constitute the bulk of the sediment, but felspar particles are nearly always present. Despite the power of the deposit to exist as steep cliffs and to have allowed the cutting of numerous rock-houses in the Kinver district, the only cementation appears to be due to the conspicuous but small amount of iron oxide around the grains. The rock either at outcrop or from borings can be broken down between the fingers with no difficulty.

Dr. F. Raw obtained, from the basal Bunter Pebble Beds of Wollaston, a pebble of lustre-mottled sandstone which, apart from its cement, was indistinguishable from Lower Bunter Sandstone. This suggests that some, at least, of the latter was cemented soon after deposition and has since been decalcified.

Examination of the outcrops immediately makes apparent the extraordinary uniformity of the deposit. The Lower Bunter consists of nothing but sand. The Lapworth Club examined every accessible exposure (476 in all, some of them each of several hundred feet in length) and no record of even the thinnest of clay bands was made. Coarse beds with pebbles were also completely unrecorded except for a thin development at one exposure—the base of the deposit where it rests unconformably on the Upper Carboniferous at Apley Park, north of Bridgnorth.

It became possible to translate this uniformity into figures by systematic examination of the Kinver core.[1] This commmenced about 100 feet below the top of the formation, and went down for a further 750 feet. Apart from about 50 feet of drift, it was in Lower Bunter throughout, so that the thickness of the formation is here not less than 850 feet. It is hardly likely to be much more, for this figure is considerably in excess of the total thickness recorded in other borings.

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[1] South Staffordshire Water Company's Pumping Station, ¼ mile N.N.E. of Kinver Church.

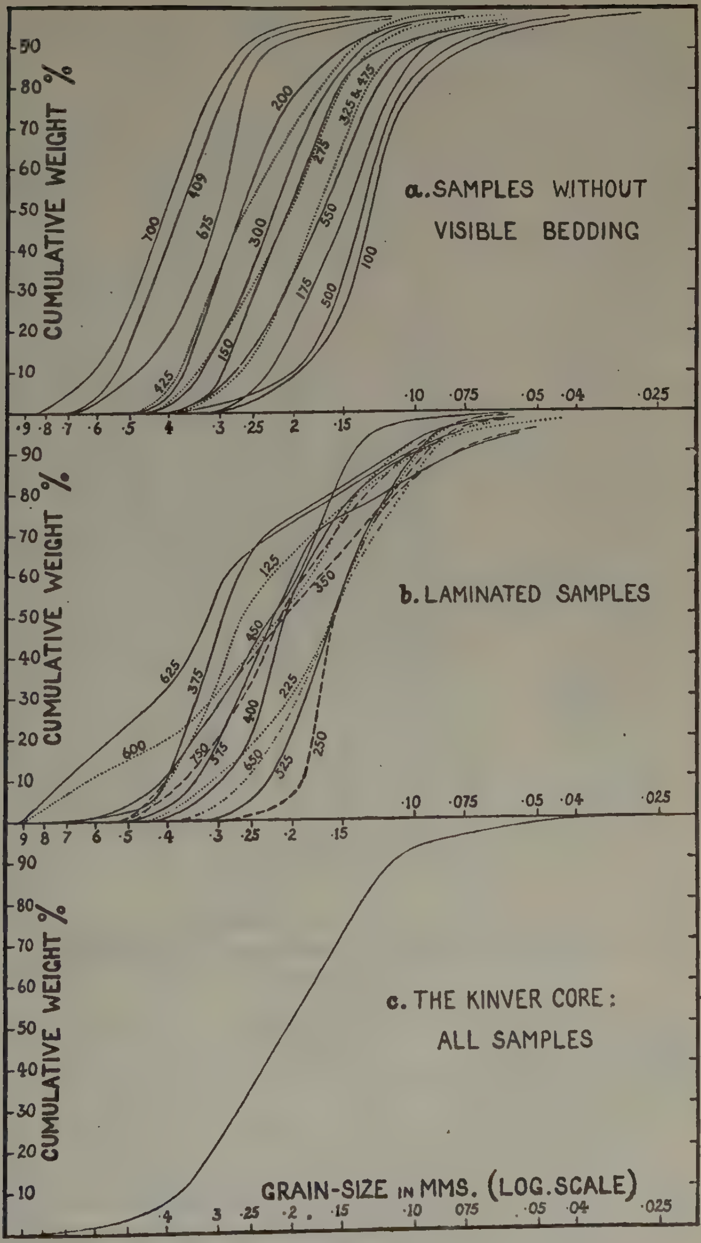
The first 100 feet of the boring was chiselled, so that the available core was 650 feet in length. It exactly resembled the Lower Bunter outcrop in its dominant red colour, slight cementation, in being cross-bedded throughout, and in being completely devoid of either clay or pebble beds. Samples were collected at 25 ft. intervals, though collection at 725 ft. depth was accidentally omitted, and an additional sample was taken at 409 feet because the sand appeared here to reach its maximum coarseness (though actually it proved to be less coarse than the 700 ft. sample).

The samples, after drying, were sieved. In a few cases the sand was first thoroughly cleaned chemically, but the results so obtained were almost identical with those from untreated specimens, and it became clear that this refinement of technique was unnecessary. Fourteen of the twenty-seven samples were perfectly uniform to the eye and showed no lamination in the small specimen. The other thirteen were visibly laminated, and from each of these a piece half an inch thick and split along the bedding was taken for crushing and sieving. These two types will be referred to in the sequel as "uniform" and "laminated".

The sieving results were plotted as cumulative graphs with the grain-size expressed logarithmically. The curves of the uniform samples are shown in Text-fig. 1, a, and of the laminated samples in Text-fig. 1, b. The second group includes a number of curves which are clearly composite, an inevitable result when the samples include layers of different degrees of coarseness. Any expression of the degree of sorting of the particles obtained from the graphs of these laminated samples will underestimate the sorting within the layers of which the sample is composed. The uniform samples, on the other hand, will give a figure which is a measure of the sorting power of the agent which deposited the sand.

The significant figures obtained from these curves follow Trask's system (Trask, 1930, 1932). In the cumulative curve, the diameters of grains corresponding to 25 per cent, 50 per cent, and 75 per cent weight are known respectively as the first quartile (Q_1), median diameter (M), and third quartile (Q_3). The Coefficient of Sorting (So) is given by $\sqrt{\frac{Q_1}{Q_3}}$ and becomes increasingly greater than 1 as the sediment departs from the ideal of perfect uniformity. The departure of the curve from symmetry (the Skewness, Sk.) is given by the expression $\frac{Q_1 \cdot Q_3}{M^2}$, and this expression equals unity when the symmetry is perfect.

In Table 1 are given the results of the analyses of the twenty-seven core samples, the 10 percentiles and 90 percentiles being included for greater precision.


a. SAMPLES WITHOUT VISIBLE BEDDING
CUMULATIVE WEIGHT %
10
20
30
40
50
60
70
80
90
700
409
675
200
300
275
325 & 475
550
100
175
500
150
425
·10
·075
·05
·04
·025
·9
·8
·7
·6
·5
·4
·3
·25
·2
·15
b. LAMINATED SAMPLES
CUMULATIVE WEIGHT %
10
20
30
40
50
60
70
80
90
125
350
450
625
375
400
225
600
150
575
650
525
250
·10
·075
·05
·04
·025
9
8
7
6
·5
·4
·3
·25
·2
·15
c. THE KINVER CORE: ALL SAMPLES
CUMULATIVE WEIGHT %
10
20
30
40
50
60
70
80
90
GRAIN-SIZE IN MMS. (LOG. SCALE)
·4
·3
·25
·2
·15
·10
·075
·05
·04
·025

TEXT-FIG. 1.

TABLE I.—MECHANICAL ANALYSES OF CORE SAMPLES FROM KINVER.

Depth from surface in feet.	Remarks.	10 percentile.	1st Quartile Q_1.	Median Diam. M.	3rd Quartile Q_3.	90 percentile.	Coefficient of Sorting (So).	Skewness (Sk.).
100	Uniform	·194	·151	·129	·109	·075	1·18	·99
125	Laminated	·396	·329	·265	·157	·098	1·45	·73
150	Uniform	·295	·260	·216	·165	·120	1·25	·92
175	Uniform	·230	·192	·148	·121	·096	1·25	1·06
200	Uniform	·363	·322	·268	·211	·151	1·23	·95
225	Laminated	·310	·221	·158	·123	·097	1·34	1·09
250	Laminated	·188	·175	·157	·122	·080	1·20	·89
275	Uniform	·339	·273	·210	·162	·128	1·30	1·00
300	Uniform	·333	·279	·224	·177	·135	1·25	·98
325	Uniform	·270	·220	·176	·139	·109	1·26	·99
350	Laminated	·401	·321	·210	·126	·095	1·60	·92
375	Laminated	·402	·350	·295	·197	·112	1·33	·79
400	Laminated	·295	·242	·210	·155	·100	1·25	·85
409	Uniform	·540	·465	·375	·301	·249	1·24	1·00
425	Uniform	·377	·330	·260	·187	·143	1·33	·91
450	Laminated	·410	·317	·225	·167	·141	1·38	1·05
475	Uniform	·261	·223	·178	·141	·111	1·26	1·00
500	Uniform	·200	·162	·135	·114	·083	1·19	1·01
525	Laminated	·227	·194	·158	·125	·100	1·25	·97
550	Uniform	·279	·222	·170	·133	·101	1·29	1·02
575	Laminated	·338	·284	·223	·146	·078	1·40	·83
600	Laminated	·625	·345	·213	·149	·111	1·52	1·13
625	Laminated	·710	·482	·318	·186	·103	1·61	·89
650	Laminated	·257	·206	·159	·115	·092	1·34	·94
675	Uniform	·480	·373	·302	·269	·227	1·18	1·10
700	Uniform	·615	·510	·410	·328	·267	1·25	1·00
750	Laminated	·364	·281	·215	·145	·104	1·39	·86

All dimensions in millimetres.

If the fourteen uniform samples are considered separately from the laminated ones, the following results may be tabulated :—

TABLE II.

	Uniform Samples	*Laminated Samples*
Median diameter ranges from	0·129 to 0·410 mm.	0·157 to 0·318 mm.
Average median diameter	0·232 mm.	0·216 mm.
Coefficient of sorting ranges from	1·18 to 1·33	1·20 to 1·61
Average coefficient of sorting	1·25	1·39
Skewness ranges from	0·91 to 1·10	0·73 to 1·13
Average departure of skewness from unity is	0·03	0·12

These figures bring out clearly two of the three most striking features of the Lower Bunter sands—their fineness of grain, and their high perfection of sorting. The other dominant feature is the shape of the particles. Examination of the sieved samples always showed perfect millet-seed grains above 0·25 mm., and almost always above 0·18 mm. Grains below this size showed considerable rounding, but departed more and more from spherical shape as they became smaller.

If the weights retained on the various sieves in all twenty-seven cases are added together, there results a group of figures which may be taken to represent the whole 650 feet of core examined—or, for all practical purposes, the Lower Bunter as a whole. These figures are expressed graphically in Text-fig. 1, c, and the curve brings out forcibly the amazing uniformity of the deposit. The following facts summarize the curve :—

(1) The median diameter is 0·202 mm. (it should be noted that this is slightly lower than the mean of the twenty-seven individual median diameters.

(2) The skewness is 1·00, indicating perfect symmetry. (This should be the case in any very large assemblage of particles, irrespective of the perfection of sorting, but it provides a satisfactory check on the correctness of the apertures in the sieves.)

(3) The coefficient of sorting has the strikingly low value of 1·41.

(4) Not a single grain exceeded 0·9 mm. in diameter; only 3·3 per cent exceeded 0·5 mm.; 80·9 per cent lay between 0·5 mm. and 0·125 mm.; 97·6 per cent exceeded 0·0625 ($\frac{1}{16}$) mm.

Specimens collected at the outcrops of the formation were also mechanically analysed. From the Bridgnorth outcrop sands were obtained (amongst other samples) from near the base, and at the extreme summit of the formation which were somewhat coarser than any occurring in the Kinver core (which failed to show the limits of the formation). Eleven of the samples were small pieces (eight uniform and three laminated) and five were bulk samples collected from about a foot of sand. Five samples from the Wollaston pits were also examined, of which one was a uniform fragment, two were laminated, and two were bulk samples. It is unnecessary to give more than a brief tabular summary of these results.

Table III.—Summary of Mechanical Analyses of Outcrop Samples.

	Range of Median diameters	Range of Coefficients of Sorting	Mean Coefficient of Sorting
	mm.		
Bridgnorth outcrop. 16 samples collected between Sheriff Hales and Eardington .	0·219–0·780	1·07–1·88	1·29
Bewdley–Kinver outcrop. 2 samples from Bewdley and 1 from Kinver	0·206–0·307	1·16–1·55	1·35
Wollaston outcrop. 5 samples .	0·200–0·410	1·17–1·71	1·42

In using the mechanical analysis figures as a means of deciding the mode of origin of the Lower Bunter, we are concerned primarily with assessing the significance of two factors—the small size of the particles (and yet absence of finer silt and mud) and the degree of sorting.

Size of Particles.

Udden (1898) states that the particles of wind-blown deposits are almost entirely between diameters of $\frac{1}{16}$ mm. and 1 mm. (compare the Kinver core, Text-fig. 1, c, with 97·6 per cent between $\frac{1}{16}$ and $\frac{9}{10}$ mm.).

Twenhofel (1932) quoting, amongst others, Udden and Sokolow (1894), states (pp. 75, 82) that true wind-deposited particles rarely exceed 1 mm., while particles below $\frac{1}{16}$ mm. are almost absent. He regards the absence of the very fine and coarse particles as a characteristic of wind-deposition in contrast to water deposition.

McKee (1934) in a paper on the Coconino Sandstone (a deposit very close in character to our Lower Bunter) compares Udden's figures for fifty modern dune sands with figures for thirty-six marine sands. Samples with median diameters below 0·25 mm. comprise 86 per cent in the first case and only 25 per cent in the second. In the Kinver core (omitting the one sample not taken at the 25 ft. interval) the figure is 73 per cent.

Bagnold (1935) gives histograms of seven sands from the Libyan desert, whose median diameters range from 0·17 mm. to 0·35 mm.

An Aberdeen dune sand quoted by Holmes (1921) from Boswell has a median diameter of about 0·35 mm.

Sorting of Particles.

It is generally agreed that, among the agents of deposition, wind is by far the most efficient in sorting particles to a uniform size. Thus, Udden (1898) states that over 80 per cent. of dune particles lie between the diameters of $\frac{1}{2}$ and $\frac{1}{8}$ mm. (Compare the figure of 80·9 per cent. in the Kinver core.) Bagnold (1935) gives seven curves of Libyan desert sand, of which four are intended to illustrate composite sorting. Even in these, however, the Trask coefficient of sorting works out at 1·40, 1·51, 1·71, and 3·27 respectively, while in the three cases of normal sand the figures are 1·18, 1·34, and 1·35. The sand quoted by Holmes (see above) has a sorting coefficient of approximately 1·09.

In contrast with these figures, those obtained from sediments due to all other agencies but wind indicate a much more imperfect degree of sorting. Marine sediments approach closest to aeolian ones, and in certain glass-sands—amongst others, those of the Lower Greensand—the Trask coefficient of sorting is close to 1·10, and indicates as perfect a sorting as in any dune sand. Considered alone, then, the low values for the coefficient of sorting in the case of the Lower Bunter are not conclusive evidence in favour of aeolian origin.

But it must be realized that well-sorted marine sands are exceptional, and that also, even in areas of marine glass-sands, such perfection of sorting as is quoted above is not maintained over great thicknesses of deposit. Far more representative of marine deposits are the 161 samples examined by Trask (1932). Selecting only those with median diameters of 0·100 mm. or more, there results a group of twenty-four samples comparable in grain-dimensions with the Lower Bunter sands. In this group the coefficient of sorting ranges from 1·26 to 9·45, and averages 2·57.

Comparing these figures with the low values for the Lower Bunter, and realizing that these latter values are maintained all over the outcrop and at all horizons in the formation, and also bearing in mind the small size of the sand particles in the Lower Bunter and the invariable presence of millet seed grains, there seems no alternative to the view that all the Lower Bunter in the area examined is old dune sand. This conclusion was reached quite independently from the study of the cross-bedding (which is inexplicable on any other hypothesis) and before systematic mechanical analysis of the sediment was undertaken. But although this conclusion may not appear very different from many other general statements which have been made about the Bunter, it is important to realize that of the three divisions of the formation in this part of the Midlands, the Lower only is consistently of desert origin. Indeed, if one may anticipate work which is now in progress, it is probable that in the other parts of the formation true aeolian deposits are almost or entirely absent.

II. The False-bedding of the Lower Bunter.

No systematic investigation of the false-bedding of the deposit has previously been undertaken, though Robertson (in Whitehead and others, 1928, p. 121) notes certain points and also briefly compares the false-bedding with that of the Upper Bunter. As a result, he suggests aeolian deposition for the lower division and possibly an aqueous origin for the upper—a conclusion with which we agree. The four points which he notes for the current-bedding of the Lower Bunter are :—

(1) The existence of distinct and independent lenticular units of current-bedding.

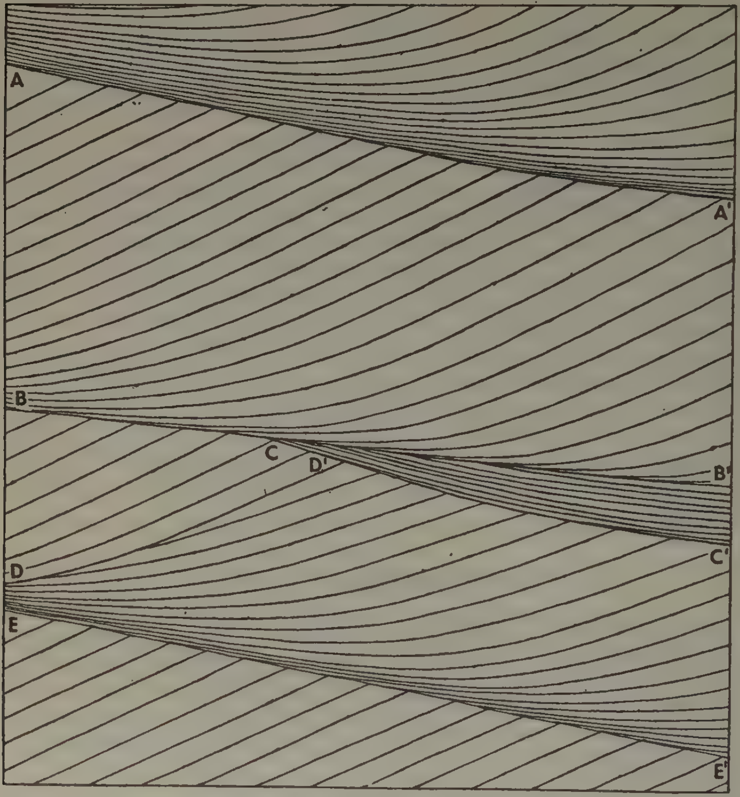
(2) The tendency of current-bedding in these units to take on as far as possible a basin-shaped form.

(3) The absence of any curve with convex side upwards.

(4) The apparent predominance of dips in a direction between north and west.

From the second conclusion we should differ, for it seems a striking feature of the false-bedding that anything approaching the symmetry of a basin or channel is rare. Indeed, the most obvious character of the false-bedding is the existence of beds with dips of between 20° and 30° usually, truncated above by planes with a more gradual slope.

The essential features of the bedding can, however, best be discussed by reference to Text-fig. 2, which epitomizes the arrangement in the Lower Bunter. AA^1, BB^1, CC^1, DD^1, and EE^1 are planes of discontinuity which will be referred to hereafter as "erosion planes". Beneath, for example, AA^1 the bedding is steep and relatively widely-spaced. Above AA^1 the bedding is closely-spaced and for a short vertical distance parallel to the erosion plane, but if any bed is traced laterally to the right it thickens and in so doing changes its dip from a gentle one to the right to a steep one to the left. Similarly the beds truncated by AA^1, which at first dip down steeply and constantly to the left, eventually thin if traced down

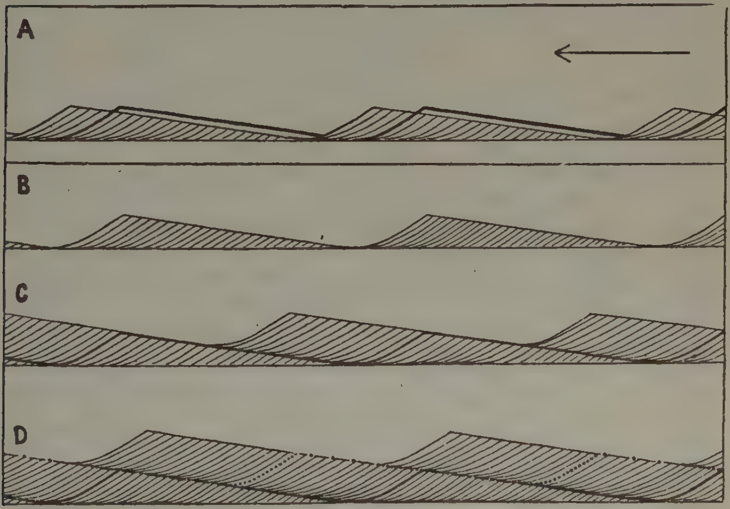


Text-fig. 2.

far enough, change their direction of dip, and finally run gently up a lower erosion plane (BB¹). The distance between successive erosion planes may in one case be only a few feet, or may be near to 100 feet.

This type of cross-bedding can only be explained, we believe, on the assumption that it represents a cross-section of barchan dunes, with the "deposition planes" (such as BA¹ on Text-fig. 2) representing successive positions of the steep leeward side, and erosion planes such as AA¹ the gently-inclined windward slopes. "Seif" dunes, with their sides equally inclined, and parallel to the wind direction, would not give such a result; nor would any type of sub-aqueous deposition. The cross-bedding, however, can even then only be explained if we visualize barchans in a "sand-sea" which is steadily filling a desert basin.

Consideration of Text-fig. 3 will make this clear. In Text-fig. 3, A, are represented cross-sections of dunes subject to a wind blowing from the right, which is imagined to leave the diagram carrying as much sand as it had on entry. In that case, as much sand will be picked up from or rolled up the windward slopes as is deposited on the leeward slopes. The dunes will move forward, but their general level will not rise and growth of the leeward slopes is only possible by erosion of the windward ones.



TEXT-FIG. 3.

If, however, the wind enters the area with more sand than it leaves with, deposition on the lee sides will be accompanied by less erosion of the windward slopes. A situation can be visualized where the wind, striking the windward side of the dune, drops as much sand as it picks up or rolls along, and the dune grows on its lee side without any erosion of the windward one. That situation is represented in the three stages, B, C, D of Text-fig. 3. The dunes, while moving forward, will also grow upwards, and successive stages of dune outline are represented by the thick lines in C and D and the dotted one in D. The false-bedding which results is that typical of the Lower Bunter. Plane EE[1] in Text-fig. 2 represents a slope up which the front of a dune has driven forward.

If the case just considered is not quite reached, that is, if there is some erosion of the windward side but not equivalent to the deposition on the leeward slope, then the dunes will move forward along inclined planes which are nearer horizontal than the true windward slope. Erosion plane BB[1] of Text-fig. 2 represents this situation. On the other hand, so much sand may be brought in from outside sources that actual deposition may occur on the windward slope and produce the result seen above AA[1] in Text-fig. 2.

So far we have only considered dunes in two dimensions. We must also allow for the crescent-shaped outline, with its axis in the direction of the wind. Any alteration of wind direction (above a certain velocity depending on the size of the sand particles) causes a reorientation of the dune. On portions of both the front and back of the old dune erosion will take place, with simultaneous deposition on other portions. Indeed, Twenhofel regards frequent reorientation, with consequent lack of any consistent direction of the false-bedding, as a criterion of wind deposits. It is not, however, a feature of the Libyan barchans, which rarely depart from one fixed orientation (Beadnell, 1910), and the statistical investigation of the cross-bedding dips which follows later in this paper shows that it is not a feature of the Lower Bunter. A slight change of wind direction, with dune reorientation, however, provides one reasonable explanation for erosion plane CC[1] in Text-fig. 2 being cut off by BB[1] (both planes being windward slopes) and for DD[1] (a leeward slope) truncating earlier-formed deposition planes.

Present-day barchans show a marked difference in the angle of slope of the leeward and windward sides. For the leeward slope Beadnell (1910) gives a maximum of 32° or 33°, and Kádár (1934) a figure between 32° and 33½°. Twenhofel (1932, p. 83) quotes Thoulet to the effect that wind-blown detritus can lie at angles up to 41°, but also gives Passarge's figures (between 30° and 33°) and Cressey's for Indiana dunes (up to 32°). Actual experiment with the Lower Bunter sand gives an angle of rest of 32½°.

The slope of the windward face of a barchan is much less. Diagrams in Beadnell (1910) give angles between 2½° and 11°. Passarge's figures (quoted by Twenhofel) range between 5° and 11°, while Kádár (1934) gives 5° or 6° for the back and 10° for the sides. We may therefore assume that a barchan made of Lower Bunter sand would originally have foreset dip slopes up to 33°, and topsets not exceeding 11°.

An obvious test of our interpretation of the Lower Bunter is whether actual dip readings do show this marked contrast in angle. Since 476 exposures were examined, and 1,142 readings taken, the evidence is sufficient for statistical investigation. But the field readings do not give a correct picture, either for amount or direction of dip, since the Lower Bunter has had a subsequent tilt in a general eastward direction. It is necessary first to correct for this tilt.

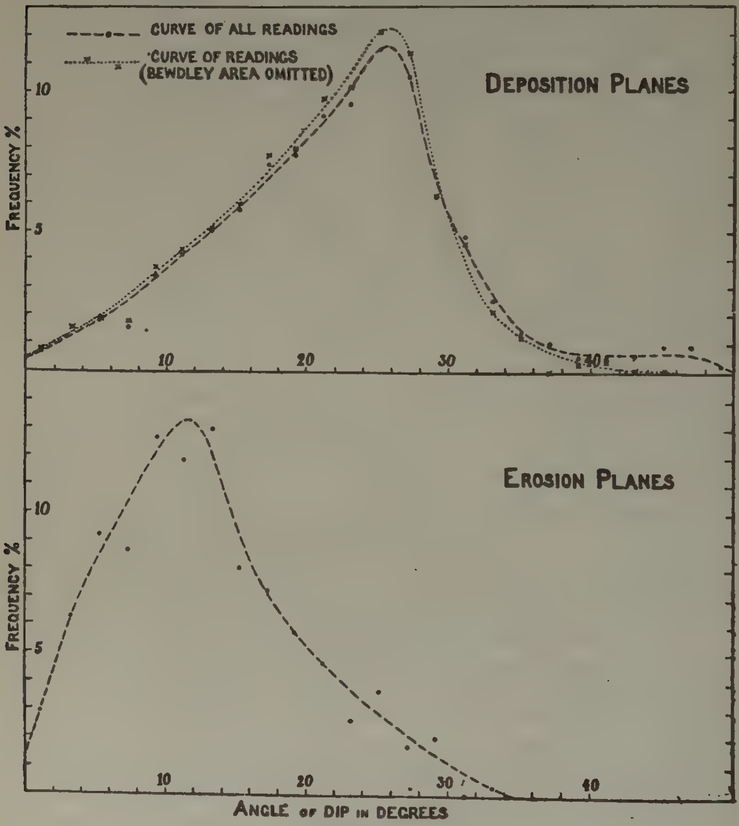
The Lower Bunter cannot be assumed to have a level base; it has a channelled upper limit, and every portion between these two surfaces is false-bedded. Hence there is no means of judging the subsequent tilting by observations in the deposit itself. Immediately east of each outcrop of Lower Bunter, however, the Middle Bunter Pebble Beds occur and in these can be found a few beds of clay or silt, with upper and lower surfaces and intermediate bedding planes all parallel. Such beds can be assumed to have been originally horizontal, and their dip measures the tilting of the Middle Bunter. We can only assume that the Lower Bunter has been similarly inclined; and on this basis we can apply a correction, varying in amount and direction, along the outcrops. Usually this correction is small (4° or 5° at most), but in the Bewdley region, where the Bunter is strongly tilted against a fault, the Middle Bunter is inclined as much as 30°, and even this correction is probably insufficient for the lower formation.

After the field readings had been converted to "corrected readings", the evidence was susceptible to statistical examination. The readings fell naturally into two groups—dips taken on bedding planes (deposition dips) numbering 793, and those taken on erosion planes, totalling 349. The frequency distribution of these two series is shown in Text-fig. 4. In the upper diagram the dotted curve is probably the more reliable, for it omits the sixty-eight readings of the Bewdley area where some of the uncorrected dips near the fault exceeded 60°, and a reliable correction was difficult to assess.

It will be noted that only 4·6 per cent of the corrected deposition dips (dotted curve) exceed 33°, and these are sufficiently explained by errors in original readings and correction. There is also a strong maximum in the curve at 26°, that is, the predominant dip is near to the theoretical maximum slope, as it is on the front of modern barchans. In marked contrast with this, the most frequent angle of the erosion planes is 11½°, and it is believed that the contrast of these two angles furnishes a final convincing proof of the barchan origin of the Lower Bunter cross-bedding.

The Lower Bunter, being in all cases nearer to the big fault dislocations than the Middle Bunter, may well have had a slightly greater subsequent tilt than the latter; yet the only correction we could apply was based on the dip of the clay bands of the Pebble Beds. Bearing this in mind and realizing also that the deposition planes face predominantly to the west (as will be shown below), it is easy to see why the most frequent angle of 26° in the deposition planes is slightly less than might be expected, and the erosion plane angle of 11½° slightly greater. Subsequent compaction of the sediment would also lower the value of the most frequent angle of deposition, but it is clear that no great effect can be ascribed to this cause.

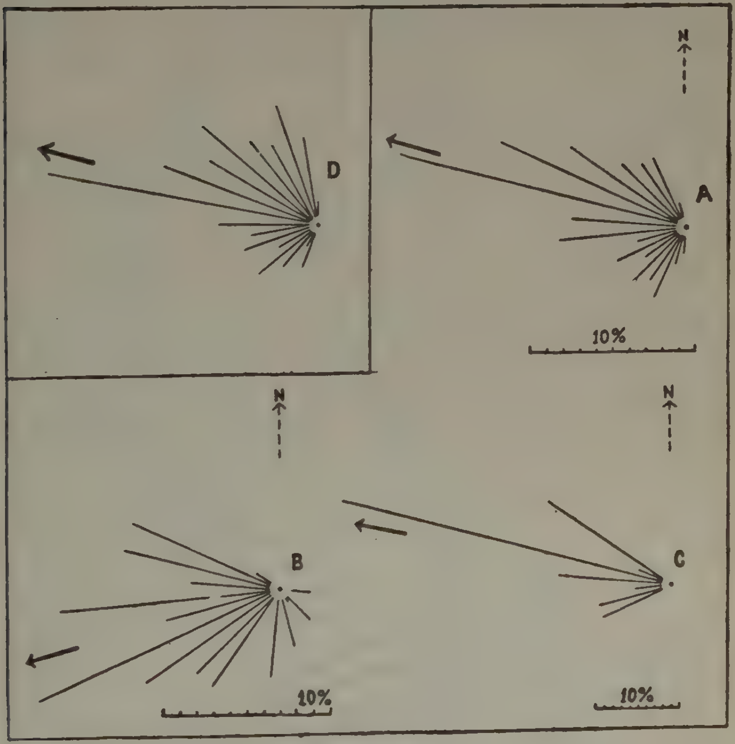
It will be noted that although the erosion plane curve shows a marked peak at 11½°, numerous readings exceed this figure. If, however, Text-fig. 2 is examined it will be seen that the heading of "erosion planes" includes a plane such as DD¹ as well as AA¹, BB¹, CC¹, and EE¹. The first is in a very different class to the other four, being formed on the front of the dune, and capable of having an angle as high as 33°. To separate the erosion planes into two groups would have prejudged the issue, but consideration of both sets together explains why a number of angles exceed the peak figure of 11½°, and why the erosion plane curve of Text-fig. 4 continues as far as 33°.



Text-fig. 4.

III. False-bedding and Wind Direction.

The "corrected" dip readings were next examined in order to see whether they showed any constancy of direction. Considering first the deposition planes, it was realized that these included not only the bedding on the steep leeward side of the dunes, but also the thin contrary-dipping sediments which run for some distance up the windward slope. It was decided, therefore, to consider only those deposition dips which, after correction, were 15° or over in angle. These could reasonably be assumed to represent the leeward dune slopes.



Text-fig. 5.

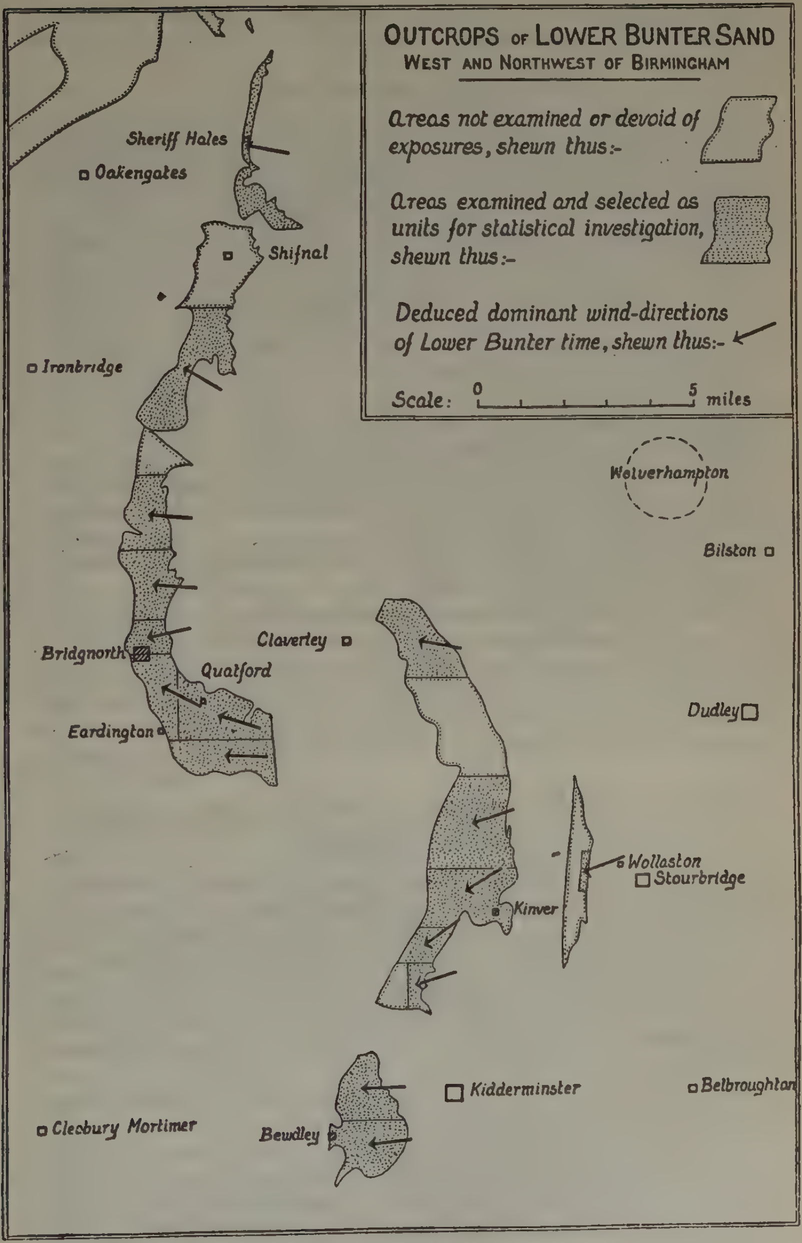
The outcrops were then divided into areas which included, as far as possible, from fifty to seventy of such readings. In the Wollaston and Sheriff Hales units, and the one east of Claverley, the number of readings had perforce to be considerably less than this through lack of exposures; while some parts of the outcrop had to be omitted owing to drift covering. It was not practicable to subdivide the outcrop also on the basis of geological horizon, for the great thickness of sandstone contains not a single "marker" by which it could be subdivided. Consideration of the results, however, shows that there is no vertical change in the average direction of cross-bedding.

The direction of the deposition dips of 15° or more were then plotted for each unit of outcrop, and revealed immediately a striking orientation. It is unnecessary to reproduce all the sixteen diagrams, but in Text-fig. 5, three are given which typify all the results. Text-fig. 5, A (the Quatford unit with sixty-four readings), is one of the best, but at least two others were as good. Here, all the readings were grouped within 160° of arc, and it becomes possible to say that the thickened arrow of Text-fig. 5, A, represents the dominant wind direction.

Text-fig. 5, B (the southern unit of the Kinver outcrop, with fifty-seven readings) is selected to illustrate a normal grouping of dip directions, and this diagram would represent almost any of the unit areas. Finally, Text-fig. 5, C (the area east of Claverley with only eleven readings) is typical of those areas where exposures are few. Because of the paucity of readings there is a fictitious concentration of the directions and a too-pronounced maximum.

The mean direction of dip (indicated by dark arrows), was taken to represent the dominant wind direction of the area. The deduced wind directions for all area-units are shown on Text-fig. 6, and have the same striking agreement amongst themselves as have the deposition dips in any one area. They range between W. 36° S. and W. 31° N., and the mean position is W. 4° S. (or for all practical purposes, a wind blowing directly from the east).

It must not, however, be forgotten that we are considering the dip of beds laid down on the fronts of barchans, which are considerably curved. Therefore, even if the wind blew only from one fixed direction, the directions of deposition dips would vary over a wide sector of a full circle. It is instructive to realize how wide this variation is. Beadnell (1910) gives scale diagrams of five dunes drawn in relation to the north wind of the Libyan desert which had shaped them. By enlarging these figures photographically, and marking on the front of the dunes points at equal spacing, it is a simple matter to work out the diagram of dip directions which would result with an invariable wind direction. Text-fig. 5, D, resulted from Beadnell's figures. The thickened arrow is the wind direction, and it has been turned (together with the rest of the diagram) so that it is parallel to the deduced wind direction of Text-fig. 5, A. It will be seen that the latter diagram shows no more variation than do the five Libyan dunes where the depositing wind had a known direction. Hence it seems reasonable to state that an east wind was not merely the dominant wind affecting the Lower Bunter desert, but that it was essentially the only wind of sufficient force to transport sand. There existed, then, a situation as in the Libyan desert to-day, where all the sand is moving in one direction (a direction which curves somewhat as the desert is crossed). We cannot expect to be able to


OUTCROPS OF LOWER BUNTER SAND
WEST AND NORTHWEST OF BIRMINGHAM
Areas not examined or devoid of exposures, shewn thus:-
Areas examined and selected as units for statistical investigation, shewn thus:-
Deduced dominant wind-directions of Lower Bunter time, shewn thus:-
Scale: 0 5 miles
Sheriff Hales
Oakengates
Shifnal
Ironbridge
Wolverhampton
Bilston
Claverley
Bridgnorth
Quatford
Eardington
Dudley
Wollaston
Stourbridge
Kinver
Kidderminster
Belbroughton
Cleobury Mortimer
Bewdley

Text-fig. 6.

deduce any such curve in wind direction in the relatively small area of Trias desert examined.

Direction of "Erosion Planes".

Considering the great sweeping curve of the windward side of a barchan, and considering also that our readings of erosion planes included those cut out of the leeward slopes, it was not considered probable that any marked orientation of these would be seen. It was not possible to check this in each unit area, for readings were insufficient in number. Considering, however, the outcrops as a whole, and dividing the erosion plane slopes into three groups according to amount of dip, the following statements may be made:—

(1) Erosion planes up to 10° dip (121 in number) showed no special orientation about any direction.

(2) Erosion planes between 10½° and 20° (146 in number), which should chiefly belong to the lee side of the dunes, had 71 per cent of their number in the western (leeward) sector.

(3) Erosion planes above 20° (forty-seven in number), which should occur only on the lee side of the dunes, had 79 per cent of their number in the western sector.

Hence the erosion planes confirm the evidence of wind direction deduced from the deposition planes.

It may be noted that the mechanical analysis figures, in a broad way, also support this conclusion. The average coefficient of sorting for the Wollaston area is 1·42 (though based only on five samples), for Kinver 1·32, and for the Bridgnorth outcrop 1·29, indicating a progressively more perfect sorting from east to west—as would be expected with a westerly drift of the sand.

IV. The Relation of the Lower Mottled Sandstone to the "Mercian Highlands."

Lapworth long ago gave the name of the Mercian Highlands to the high land formed in the Midlands during the Hercynian orogeny. Those highlands (or at least, that part of them which ran across South Staffordshire and North-West Warwickshire) lay east of the sand desert we have been considering, and hence must have fulfilled the double function of abstracting moisture from the prevailing east wind, and of providing the material to build up the sand sea.

Eastwards from our district the Bunter Pebble Beds extend over part of the Mercian highlands, though not for many miles; but the Lower Mottled Sandstone is invariably absent. There exists, however, another much thinner formation which Boulton (1933) has shown to be Triassic. He demonstrated that it extended from the Cannock district in the north, through Barr Beacon and Hamstead, to underground occurrences in Central Birmingham;

while subsequent temporary exposures have revealed its presence south of Northfield. This group, then, which for the purposes of the present paper we can refer to as the Barr Beacon Group, has a known north–south extension of 24 miles, but a maximum east–west width of about six. Between it and the outcrops of Lower Mottled Sandstone lies a tract of country, never less than 9½ miles wide, in which the lowest Triassic rocks cannot be observed.

Boulton raised the point as to whether the Barr Beacon Group was the equivalent in time of the Lower Mottled Sandstone, and suggested that such might be the case (though he also suggested that the coarse breccias of Central Birmingham bore-holes might be the high-ground equivalents of Bunter Pebble Beds). The Barr Beacon Group rarely exceeds 100 feet in thickness, and hence is only a fraction of the amount of Lower Mottled Sandstone to the east; but Boulton visualized the Barr Beacon Group as a scree deposit derived from the highlands, cloaking the lower slopes of these hills and spreading out as water-deposited sands with thin strings of scree material on the piedmont plain. If such a deposit were formed at the edge of a desert basin it would be expected to be thinner than the dune sands in the centre of that basin, so that on this score no objection to the correlation of the deposits can be raised. The junction of the Lower Mottled Sandstone and the Pebble Beds seems always to be a channelled surface, suggesting a time break, but not necessarily a big one; the Barr Beacon Group also often has this relationship to the Pebble Beds, though in several places (including bore-holes) a gradual passage is observable. Hence the Barr Beacon Group is not older than the Lower Mottled Sandstone, but it might be newer or, in part at least, equivalent. Boulton (1933, p. 72) expressed the possibility of the two deposits being of similar age when he wrote :—

> " . . . the strong winds blowing from the Mercian highlands towards the warm, low-lying region to the west, may have accumulated the sands of early Bunter time in that region, while erosion and breccia-formation characterized the highlands to the east."

This statement, it will be noted, forecasts the view of a prevailing east wind which has been demonstrated from the false-bedding of the Lower Mottled Sandstone. Knowing now that the dune sands were derived from the Mercian highlands, and that, by comparison with present-day deserts, they must almost certainly have passed laterally into a fringe of mixed gravel and sand spread out at the foot of the highlands by intermittent stream action, it seems extremely probable that the two Lower Bunter deposits are equivalent in age.

It has to be admitted that the heavy minerals give no confirmation of this (Fleet, 1927), for there are differences in the two deposits, of which the most notable is a markedly lower amount of zircon in the Lower Mottled Sandstone. But in assessing the significance of this fact, it is important to realize that the Barr Beacon beds were sampled at the type locality itself, whereas the specimens of Lower Mottled Sandstone examined by Fleet came from outcrops more than 15 miles west of Barr Beacon, and also from 2 to 14 miles south of its latitude. Hence, on the assumption of a prevailing east wind, no real comparison of these figures is possible unless a striking uniformity in the composition of the Mercian highlands is assumed. It is improbable that such was the case.

The false-bedding of the Barr Beacon Group was systematically examined by the Lapworth Club. It was thought possible that wind- and water-deposited beds might intercalate, but no evidence of the former was detected. The characteristic cross-bedding is that of channels, and this, together with the occurrence of breccia strings and occasional clay bands in the sands, indicates fluviatile action rather than aeolian. If, then, the Barr Beacon Group and Lower Mottled Sandstone are equivalent, the transition from aqueous to aeolian deposition occurs in the intervening unknown strip of country, at least 9½ miles wide, over most of which the Lower Bunter has been removed.

One fact possibly of significance in this connection was, however, obtained from the examination of the Barr Beacon Group. The sands which do not contain the breccia layers are remarkably well sorted and of similar grain-dimension to the true aeolian sands. Eleven samples varied in median diameter from 0·135 to 0·435 mm. and averaged 0·220 mm.; their Trask coefficients of sorting ranged from 1·24 to 1·53 with a mean of 1·39. This last figure compares very closely with the Lower Mottled Sandstone, but is unexpectedly low if we visualize the Barr Beacon Group as due solely to intermittent stream action (in which sorting is poor). It can be explained if we regard the Barr Beacon Group as a desert-fringe deposit, subject for periods to wind action forming small dunes and well sorting the sand, with each such period brought to a close by a rainstorm and a flush of water from the hills, which destroyed the thin dune bedding —or at least so dissected it that its characteristic features were unrecognizable.

Therefore, although it is realized that the correlation of the Barr Beacon Group and the Lower Mottled Sandstone is as yet not free from uncertainty, it is also felt that the mechanical analyses strengthen Boulton's tentative suggestion that the two formations are equivalent.

V. Summary.

The Composition of the Sand.

The Lower Bunter consists of sand whose average grain size is about ·2 mm. Particles below 0·05 mm. or above 1 mm. are virtually absent.

The fineness of the sand and restricted limits of size variation in the whole thickness of the deposit, and the high perfection of sorting in individual samples indicate an aeolian origin.

The False Bedding.

No true bedding exists in the Lower Bunter examined.

The false-bedding is only explicable on an aeolian origin. It is argued that it must represent cross-sections of barchan dunes advancing in a sand sea that was steadily increasing in thickness.

The frequency distribution of the values of the false-bedding dips confirms this interpretation.

The directions of different types of false-bedding indicate that transport and deposition was effected almost entirely by a prevailing east wind.

Relation of the Lower Bunter to the Mercian Highlands.

The establishment of an easterly origin for the sand indicates that the " Mercian Highlands " of the Birmingham district were the source of sand supply.

Arguments are adduced towards the correlation of the Barr Beacon Beds and the Lower Bunter Sandstone, the former being regarded as the thin piedmont spread of scree material fringing the desert.

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REVIEWS.

SILICATE ANALYSIS. By A. W. GROVES. pp. xxii + 230, 11 text-figures. London: Thomas Murby and Co., 1937. Price 12*s.* 6*d.*

THE opening chapters deal briefly with the laboratory equipment, reagents, and operations, crushing and sampling, and the constituents to be determined. A minimum of thirteen should apply to all analyses, but the possible presence in significant amount of twenty-one others is discussed. The normal methods for silicate rocks are described in ninety pages, instructions for the actual procedure being printed in large type to facilitate use at the bench, and twenty-five further pages are devoted to special methods and applications. The methods recommended are orthodox, with minor modifications suggested as the result of experience; total iron and titania are determined by a pyrosulphate fusion, alkalis by the Lawrence Smith method without the use of a special crucible, and for combined water an absorption apparatus is preferred to the Penfield method. The book concludes with sections on errors and check calculations and an interesting chapter on geochemical data. The foreword by Professor Holmes, raises some rather contentious matters in a book intended for general use both by chemists and by geologists.

F. C. P.

A DESCRIPTIVE PETROGRAPHY OF THE IGNEOUS ROCKS. Vol. 3, THE INTERMEDIATE ROCKS. By A. JOHANNSEN. pp. xiv + 360, 1 plate, 179 illustrations. University of Chicago Press, 1937. London: Cambridge University Press. Price 21*s.*

THE first volume of this comprehensive work (Introduction, textures, classifications, and glossary, 1931) included a description of the author's classification used in the succeeding systematic volumes. The second volume (1932) dealt with the quartz-bearing rocks of families 0 to 8. The "intermediate" rocks of the present volume are those of the syenite-diorite-gabbro series and their extrusive and hypabyssal equivalents, constituting families 9 to 12. Detailed accounts of the origin and usage of the various rock names, containing much of interest and supported by copious references, are followed by descriptions of the megascopic and microscopic features, with modes of analysed rocks. The nomenclatorial burden of the petrographer is not lightened; apart from the compound names (such as *Leuco-Sodaclase-Trachyte*) derived from the classification and mostly published in 1919 (but here sometimes modified, as *Kalisyenite* in place of *Orthosyenite*), *Elkhornite* and *Massafuerite* are newcomers.

As a petrography, the bulk of the volume is, of course, descriptive, but there are occasional digressions upon such topics as the origin of anorthosites and the occurrence of oblique extinction in certain sections of orthorhombic minerals. The inevitable tedium of purely descriptive matter is lightened at intervals by portraits of well-known petrographers and by the range of the author's quotations—from Vergil to F. Marryat and Edward Willett! There is an index of rock names, but the fourth and last volume, which is to describe the felspathoid rocks, peridotites, and pyroxenites, will contain also the full index. The appearance of this final volume will complete an exhaustive and authoritative handbook of inestimable value to all concerned with the petrography of the igneous rocks.

F. C. P.

GOSFORTH DISTRICT. By F. M. TROTTER, S. E. HOLLINGWORTH, T. EASTWOOD, and W. C. C. ROSE. *Mem. Geol. Survey.* pp. vii + 136, with vi plates and 15 text-figs. 1937. Price 3*s.* 6*d.*

SHEET 37 of the 1 inch map, of which this memoir is a description, adjoins the Whitehaven Sheet on the south and consequently a large part of it is occupied by the sea, only about 60 square miles being land. Nevertheless, even this small area shows a lot of interesting things and a surprisingly large number of different rocks, including Skiddaw Slates, Borrowdales, Carboniferous Limestone, New Red Sandstone, Eskdale granite, and Ennerdale granophyre and an endless variety of Glacial and post-Glacial formations. It extends from Egremont on the north to well beyond the mouth of the Esk on the south; it therefore includes part of the Cumberland haematite mining area, but no coal measures. It is here that the St. Bees Sandstone has its greatest development, over 3,000 feet having been penetrated in a bore at Seascale without reaching the base. Except for a tiny patch on the northern margin, the Carboniferous Limestone nowhere comes to the surface, but haematite is worked below the New Red Sandstone in some important mines in the northern part of the area. The interesting observation is made that haematite ore-bodies are not found in the region where shales are conspicuously developed at the base of the St. Bees Sandstone. This is evidence in favour of the derivation of the iron from the red beds above, the impervious shales, where present, having acted as a barrier to its downward progress.

The account of the Glacial and later deposits gives evidence of an enormous amount of patient detailed work, but would only be really intelligible if read on the spot: this after all is the true function of a local memoir. It must suffice to say that it supports and confirms the evidence for five glacial episodes in this region.

R. H. R.

BEITRAG ZUR SYSTEMATIK UND STAMMESGESCHICHTE DER EUROPÄISCHEN PELTOCERATEN. By THEA PRIESER. Palaeontographica, Band lxxxvi, Abt. A, Lief. 1–4. 1937.

"THE object of this work is to identify the European species of *Peltoceras* as accurately as possible on the basis of an exact study of the whole ontogenetic development of sculpture and suture, to arrange them systematically on the lines indicated by Schindewolf, to trace the geographical distribution of the whole genus, and to take a view of its evolution so far as the material allows." The authoress divides the genus into four subgenera, *Peltoceras* Waagen, *s.s.*, *Parapeltoceras* Schindewolf, *Peltoceratoides* Spath, and *Epipeltoceras* Spath.

The basis of her classification is the distance of the points of bifurcation of the ribs from the umbilical margin. Thus she unites in *Parapeltoceras* (Schindewolf, 1925) "all the species of the genus *Peltoceras* whose ribs bifurcate between the middle of the whorl-side and the ventral margin, irrespective of whether they bear tubercles or not". This leads her to cut clean across most of the so-called genera recognized by Spath in his large work on Cutch; just as he in turn rearranged Buckman's identifications and declared that Buckman could have had little knowledge of the real relationships of the various forms that he figured. Thus some of the common forms are hidden in three different genera by these three authors.

One thing emerges clearly above all else, namely that the authoress is right to insist on the retention of only one genus, *Peltoceras*, keeping the other subdivisions as subgenera. Only by this means can a nomenclature be retained which continues to have any meaning or usefulness. The same applies to *Aspidoceras*, *Perisphinctes*, *Cardioceras*, and the other genera which have in recent years been subdivided beyond recognition. Each reviser will continue to rearrange and re-group, and there can never be finality. So long as these broad genera continue to be used, all is well; but if each revision of the classification is to be reflected in a complete overhaul of the binomial nomenclature, palaeontology will be choked.

Thea Prieser's system of classification has the appearance of being the most natural and simplest so far. Unfortunately, however, some more changes of subgeneric names are needed to bring the results into line with the International Rules of Zoological Nomenclature. Thus, if *Peltoceras reversum* (Leckenby) is really to be grouped in the subgenus *Peltoceratoides* Spath (1924), the name for the subgenus must be *Rursiceras* Buckman (1919), of which *P. reversum* was sole original species and therefore genotype. The reviewer, however, does not admit that *P. reversum* is rightly classified in *Peltoceratoides*. The ribs bifurcate in the middle of the whorl-sides, and on early whorls still higher, as is clearly shown on Buckman's photograph of the holotype, and other important characters are quite different. A number of other placings are also open to question on various grounds. Three of the four subgenera used seem so unhomogeneous that the impression is left that there are not enough subgenera.

The authoress blunders in making "*Peltoceras*" *angustilobatum* Brasil reappear as a *Peltoceratoides*, just twenty years after it had been asigned to the Reineckeid genus *Collotia* by A. de Grossouvre.

LES AMMONITES DE LA ZONE À *PELTOCERAS ATHLETA* DU CENTRE-OUEST DE LA FRANCE. By CH. GÉRARD and H. CONTAUT. *Mém. Soc. Géol. France*, N.S., tome xiii, fasc. 2–3, feuilles 7–19, mém. 29. 1936.

THESE authors accept uncritically all the generic names of Buckman and Spath and use them as full genera, arranged in families and subfamilies. The result is that at first sight the memoir wears an extremely learned appearance, and the ordinary palaeontologist, to find his way about, has to turn to the subfamily and family headings, with appropriate new terminations. Closer inspection reveals, however, that for 22 of the 37 so-called genera used, the authors quote wrong genotypes. Hence no less than 60 per cent of the names are liable to be more or less wrongly used.

It is useful to have these plates of an extremely interesting fauna (though about a third of the photographs should have been rejected as too bad for publication), but they would have been much more useful if an ordinary nomenclature had been used. It does not inspire confidence in the authors' two new genera, *Orbignyiceras* and *Rossiensiceras* (subdivisions of the already much-monographed genus *Hecticoceras*), to read such passages as "*Klematosphinctes* S. Buckman, 1922 . . . Type du genre : *K. mirandus* de Loriol", when *Klematosphinctes* was founded on a sole original species, *K. vernoni*, and *Perisphinctes mirandus* de Loriol was withdrawn by its own author as a synonym of *P. perisphinctoides* Sintzow, a species entirely different from *P. vernoni* and belonging to quite a different subgenus.

Often the authors seem to have gone out of their way to find wrong genotypes, as with such names as *Putealiceras*, *Obtusicostites*, *Orionides*, *Binatisphinctes*, for which the species *puteale*, *obtusicostatum*, *orion*, *binutus*, respectively, might be thought to suggest themselves automatically as the right genotypes, to anyone who had heard of them. Some other species cited as genotypes were unknown at the time when the genera to which they are attached were introduced.

The arrangement of the 18 Peltocerates in the various genera, needless to say, is for the most part quite different from that in Thea Prieser's monograph ; and there are some curious departures from Buckman's and Spath's arrangements, unsupported by reasons.

Wrong references and misprints are numerous.

W. J. A.

THE FIRST HUNDRED YEARS OF THE GEOLOGICAL SURVEY OF GREAT BRITAIN. By SIR JOHN SMITH FLETT. pp. 280 with 13 plates. London: H.M. Stationery Office. Price 7*s.* 6*d.*, postage extra.

THE oldest national Geological Survey dates its modest beginning from 1835, when Sir Henry De la Beche undertook the task of colouring geologically sheets of the Ordnance map. Its centenary coincided nearly with the transference of the greatly enlarged establishment from Jermyn Street to more commodious quarters at South Kensington. It is fitting that the double event should be celebrated by this historical record, and fortunate that the work has been placed in the competent hands of Sir John Flett, the only surviving ex-Director. It has been no light labour to bring together in readable shape data gathered from many different sources; and, if the casual reader is tempted to "skip" some of the numerical statements, these will none the less have their value for future chroniclers.

The main part of the volume consists of eight chapters tracing the history of the Survey under each of its first eight Directors. This is a rational as well as a methodical plan, for the lines on which the institution has developed from time to time have been determined largely by the personality of the man at the head. In the beginning indeed it was practically a one-man undertaking, though De la Beche seems to have received some help from certain of the Ordnance Surveyors. It may be remarked that as early as 1814 Macculloch had been given the title of Geologist to the Trigonometrical Survey of Great Britain, but this seems to have been merely a personal recognition of his single-handed work in Scotland. A like appointment for Ireland was conferred on Portlock in 1832. De la Beche, Portlock, and Murchison had all been in the Army, and a certain military tradition and discipline seems to have clung about the Geological Survey for some time after its beginning. It is on record, though Sir John does not mention it, that at one time the field-geologists wore some kind of uniform.

During the twenty years of De la Beche's rule the mapping, begun in Cornwall and Devon, spread next to South Wales, and, with a staff grown to some half-dozen men in the field, was being steadily pushed on. Sheets of "horizontal" and "vertical" sections were also published, besides some important Memoirs. A landmark was the opening of the Jermyn Street Museum in 1851. This was to house the offices of the Survey and the Museum of Practical Geology, containing the collections accumulated in the course of years. It included also the School of Mines and the Mining Records Office, but these subsequently severed their connection with the Survey.

Sir Roderick Murchison succeeded to the Directorship at the age of 63, but soon showed that he had lost nothing of his natural vigour. An excellent administrator, he was able also to exercise considerable influence in high quarters, as well as with the general public. Aided by the recommendations of a Royal Commission on the coal supply, he succeeded in obtaining in 1867–8 a large increase in the staff of the Survey, and for these he found no lack of occupation. In addition to new sheets of the geological map, many of the old sheets were issued in revised editions, and the practice of publishing an explanatory memoir for each sheet became a part of the regular routine. The style of mapping was greatly improved since early days, though a limit was set by the one-inch scale on which (except in Ireland) the field-work had to be carried on. Now, as six-inch maps became available, in Scotland and then in England, a closer survey of the ground was possible, though the results were in general reduced to the one-inch scale for publication. It was, however, Murchison's successor, Sir Andrew Ramsay, who, drawing upon his own long experience in the field, did most to improve and standardize the technique of geological surveying, and to him chiefly must be credited the high standard of performance which we have learnt to expect. Ramsay insisted too upon the adequate representation of the surface-deposits, which had too often been neglected in earlier published maps. Some sheets were issued in two editions, " solid " and " drift ".

The value of minute and accurate study in the field was triumphantly vindicated when, in 1882, Sir Archibald Geikie inaugurated his office as Director by boldly attacking the " secret of the Highlands ". How the unravelling of the complicated tectonics of the Assynt district by a strong contingent of skilled surveyors confuted the cherished beliefs of the Director himself is well known, nor will it be forgotten that he accepted the correction with admirable candour. This was not the only way in which Geikie infused new life into the Survey. Unlike his immediate predecessor, who had scoffed at " studying mountains under the microscope ", he was fully alive to the importance of petrology ; and, as the survey of the Highlands progressed, it became increasingly urgent to make some provision for this side of the work. It was done at first, not mainly by the men in the field, but by a specialist in the office : at a later time a closer connection between field and laboratory was found practicable. Towards the close of Geikie's rule, by the agency of a Departmental Committee, there was a reorganization of the staff of the Survey, accompanied by an increase of pay for its junior members. This was certainly called for : while an Assistant-Geologist began at eight shillings a day, only a very keen enthusiasm could bring in recruits of the kind desired.

The more recent history of the Survey may be briefly summarized. Sir Jethro Teall, when he succeeded to the Directorship, had been for some years Petrographer to the Survey, and under him there was a noteworthy development in this department, many of the surveyors making this a normal part of their work. Besides the continued revision of the coal-fields, attention was concentrated especially upon the survey of the Highlands, where differences of interpretation were a cause of much discussion. Colour-printing of the one-inch maps became general, tending to greater accuracy as well as cheaper production and increased use by the public. Among other changes should be mentioned great improvements in the Museum of Practical Geology. Sir Aubrey Strahan's tenure of the Directorship coincided with the Great War and early post-War years. The normal business of the Survey was practically in abeyance, and those members of the staff who were not on active service were engaged in various special investigations arising out of the war conditions. Some of the results, such as the "Special Memoirs on the Mineral Resources of Great Britain", have, however, a permanent value. The next Director, Sir John Flett, had succeeded Teall as Petrographer, and had since been Assistant-Director for Scotland. Still another reorganization took effect about this time. The Survey, which in the course of its history had been bandied about from one Government Department to another, was now attached to the Department of Scientific and Industrial Research and placed under a Geological Survey Board. The mapping of new ground was resumed. In particular, the work on the Tertiary igneous rocks of Scotland, begun in Skye under Geikie, was completed in Mull and Ardnamurchan, leading to results of wide general interest. The scope of the Survey, which had long ceased to be restricted to geological cartography, underwent further expansion. The memoirs on mineral resources were continued and in addition the Survey took over new duties in relation to such matters as fuel research, building materials, water-supply, and soils. Meanwhile the Director and some responsible members of his staff were preoccupied with a matter of immediate urgency. The Jermyn Street building was in a ruinous state, and the time for removal drew near. A formidable task had to be faced, especially in the safe transport and improved rearrangement of the contents of the Museum. How successfully this has been accomplished may be judged by all who visit the handsome new building at South Kensington.

A full account of the ceremonial opening of the new building is given in Part II of the volume, and a very useful appendix is a complete annotated list of the staff during the hundred years. There are a number of photographic plates, including portraits of the several Directors and of others whose features we are glad to recall.

A. H.

CORRESPONDENCE.

THE ZONAL POSITION OF THE ELSWORTH ROCK.

Sir,—Will you allow me, in view of Dr. Arkell's article in a recent number of the Geological Magazine, to suggest that the zonal position of the Elsworth Rock as given in my Kachh Memoir (p. 872) is unassailable. Most of your readers will have recognized that there is not much that is new in Dr. Arkell's article, except names (which may be wrong). I do not claim that my work is entirely free from errors. For example, I may have been carelessly copying an ambiguous name like "Calcareous Grit" from an old ammonite label, or used the term *perarmatus* zone, without qualifying it every time; but I naturally had in my own mind what I had elsewhere in the same work said about the same ammonite or zone, without troubling to repeat it every time I mentioned them. It is quite beyond me to see the purpose of an entirely one-sided and misleading selection of passages and species and even dates of publication; the way in which the various zonal terms are used by Dr. Arkell seems to show that he produced apparently contradictory opinions mainly in order to be able to correct them.

L. F. Spath.

British Museum (Natural History).
22nd October, 1937.

THE SUPPOSED BASAL COMPLEX IN JAMAICA.

Sir,—The so-called Basal Complex in Jamaica is again up for dispute. I would feel more confidence in it if Dr. Matley could make up his mind which rocks are to be included, or if he and Dr. Stockley could agree on this point. I have already stated my reasons for considering all the major intrusives of Jamaica to be Tertiary, including the granodiorite which replaces all the sedimentaries up to and well into the White Limestone. Until a further visit to Jamaica may possibly reveal more exposures, I have nothing more to say on this question. As regards the rocks which look like and behave in the field as hornfelses and were labelled so on my rock slices, I am well aware that some of these appear to be "igneous" under the microscope, which tends to support my contention that in Jamaica we have sedimentaries altered *in situ* into rocks that would ordinarily be classified as igneous.

Regarding Dr. Raw's diagnoses; readers will form their own opinions as to which category of "igneous" rocks a "rhyolitic glass tuff, now devitrified, with flow and perlitic texture, much quartz and epidote and some serpentine", should be placed in. Also in one of my greenish dykes from near Bath, Dr. Raw should not describe holes made in grinding the slice as "highly vesicular structure".

His diagnosis of a "Jaspery rock which may be an altered chert", from the section below the Lazaretto, is interesting because the "hornfels" and marble there is quite clearly a product of alteration of the White Limestone (Geol. Mag., June, 1936, p. 261). I attributed this to gases associated with an intrusion, but Dr. Matley ridicules this idea. Those who work in Wales and Anglesey may not always realize the ferocity of action of a volcano of the West Indian type. Take the case of Mount Pelée on 8th May, 1902; "an inhabitant of Morne Rouge who was watching the volcano at the moment of the catastrophe said there were seven luminous points on the volcano's side just before it burst." This looks like gases heating their way through the rock. I have bottles from St. Pierre, six miles from the crater, in which a single whiff of the *nuée ardente* has crumpled up and devitrified to a fibrous wollastonite-like material the neck or other part, the glass below it showing a distinct perlitic-like structure.

The Serge Island marble has to me the fine grained, loosely rolled-out appearance of a late formation. There are similar but much more extensive marbles and crystalline limestones in the Northern Range of Trinidad which are all of Upper Cretaceous age. What is needed is a resurvey of the whole island, not merely of the Kingston district, but in view of the greatly weathered condition of the country I doubt if much improvement could be made on the Sawkins map of 1864.

C. T. TRECHMANN.

CASTLE EDEN,
CO. DURHAM.
November, 1937.

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